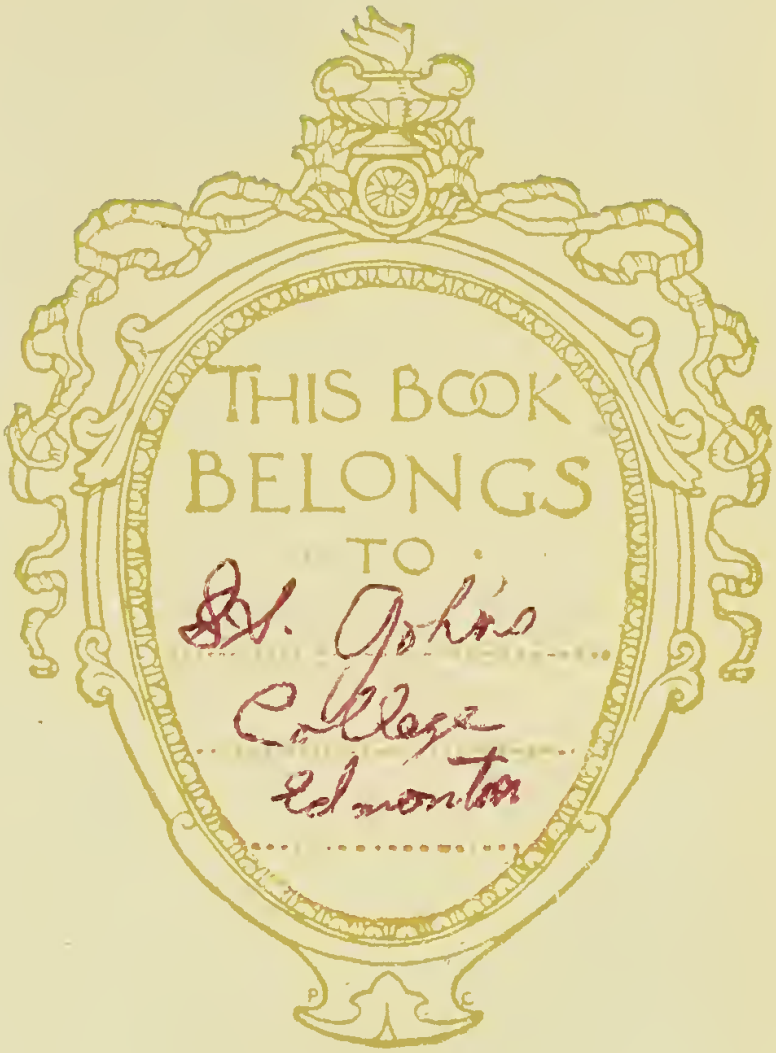
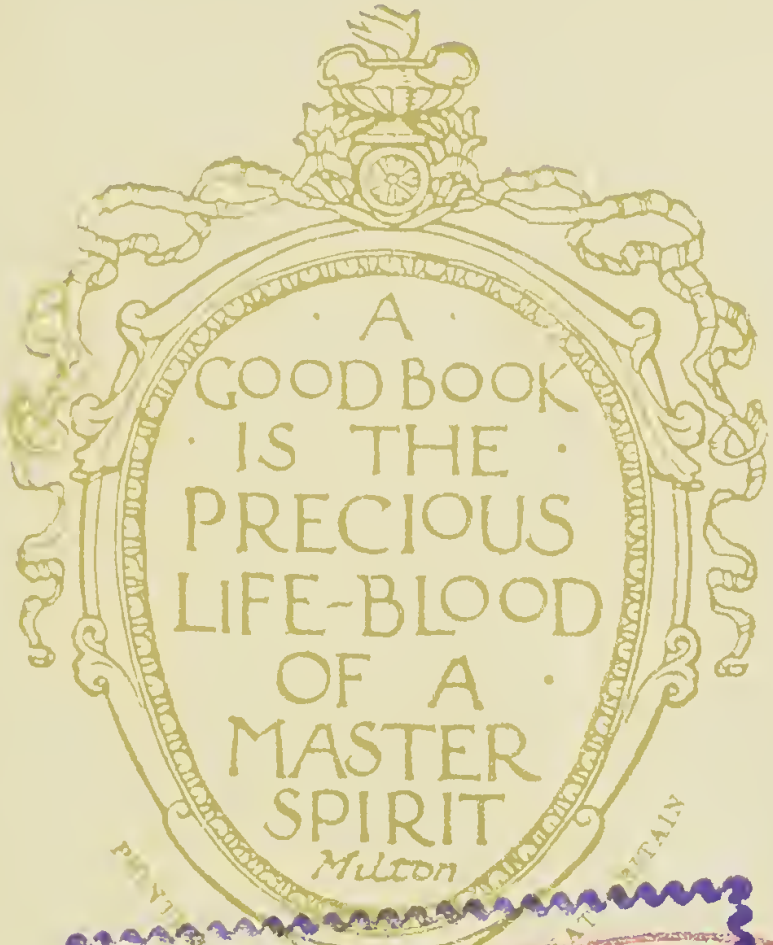

THIS BOOK
BELONGS
TO
St. Johns
College
Edmonton

Individual Reading. grade XI



Bibliothèque
des ÉLÈVES
COLLÈGE ST-JEAN
8406 - 91e Rue du
Edmonton, - Alta.
2 39
Iden.....
Place.....

BIBLIOTHEQUE
du
COLLEGE SAINT-JEAN
EDMONTON; ALBERTA

Digitized by the Internet Archive
in 2018 with funding from
University of Alberta Libraries

https://archive.org/details/chemicalhistoryo00fara_1

The KINGS TREASURIES OF LITERATURE

GENERAL EDITOR
SIR A·T·QUILLER COUCH

2 33
Bibliothèque
des ELEVES
COLLÈGE ST-JEAN
8406 - 91e Rue
Edmonton, Alta.

LONDON: J·M·DENT & SONS LTD.

CHEMISTRY
MICHAEL FARADAY

Grade XI.

THE CHEMICAL HISTORY OF A CANDLE

BY

MICHAEL FARADAY

15917

Bibliothèque

EDITED BY

W·R·FIELDING M·A·

WITH INTRODUCTION BY

PROF·J·ARTHUR THOMSON

ALL RIGHTS RESERVED
MADE IN GREAT BRITAIN AT
THE TEMPLE PRESS, LETCHWORTH, HERTS
FIRST PUBLISHED (IN THIS EDITION) 1920
LAST REPRINTED 1938

QC
16
F2

EDITOR'S NOTE

FOR this edition I have rearranged Sir William Crookes' transcription of Faraday's LECTURES ON A CANDLE, and have provided it with a few necessary connecting links. The result has been divided into sections, and new figures have been added.

I believe that this edition will serve not only as literature, but also as a useful introduction to Chemistry.

W. R. F.

CONTENTS

PAGE

MICHAEL FARADAY. By Prof. J. A. Thomson . . 7

SIR W. CROOKES' INTRODUCTION 20

SECTION

1. INTRODUCTION 23
2. WHAT ARE CANDLES MADE OF? 23
3. THE MANUFACTURE OF CANDLES 25
4. THE CANDLE FLAME 27
5. THE ZONES OF A CANDLE FLAME. DISTRIBUTION OF HEAT 44
6. FRESH AIR IS NECESSARY FOR COMBUSTION . . 48
7. IS COMBUSTION ALWAYS ACCOMPANIED BY FLAME? . 50
8. THE LUMINOSITY OF FLAME 52
9-22. PRODUCTS OF COMBUSTION OF A CANDLE . 58–132

(*a*) CARBON

(*b*) WATER (10–18)

(i.) Water exists in three states (10)

(ii.) It is a compound of hydrogen (11–14) and oxygen (14–15). Oxygen is a constituent of the atmosphere, so Faraday devotes sections 17 and 18 to the study of the atmosphere.

(iii.) Synthesis of water from oxygen and hydrogen (16).

(*c*) CARBON DIOXIDE (19–22)

19. Methods of recognising the gas
20. Its preparation
21. Properties
22. Its composition

SECTION PAGE

23. Respiration and its Analogy to the Burning of a Candle 132

24. Co-operation of the Animal and Vegetable Worlds 140

25. Fuels 143

Professor Tyndall on Faraday 149

MICHAEL FARADAY

By Prof. J. ARTHUR THOMSON

Marischal College, Aberdeen

Faraday's *Lectures on the Chemical History of a Candle* were delivered to an audience of young people at the Royal Institution in London. They were given more than once, the last occasion being in Christmas 1860. This seems a very long time ago, but the lectures remain fresh and true. For the man who gave them was a great genius who saw deeply into things and made facts live; and the way in which he coaxed the candle to yield up its secrets is a fine illustration of the way the scientific investigator goes to work. It is useful to have knowledge about things, but it is still more useful to know how that knowledge has been gained and how it may grow. If a boy reads *The Chemical History of a Candle* carefully, and, unless he is very clever, three times over, and if he puts to a candle of his own the questions Faraday asked of his, he is likely to get an idea of the method by which discoveries are made, and he may be prompted to go on to be a discoverer himself. When Faraday was a boy he was greatly interested in a simple

book, Mrs. Marcet's *Conversations on Chemistry*, and he set to work to see if the statements made in the book were true. "I made," he says, "such simple experiments in chemistry as could be defrayed in their expense by a few pence per week." Of course nothing could have kept back a genius like Faraday, but the biographical fact is that an old-fashioned book on chemistry was one of the influences that shaped his life. Now what *we* have in *The Chemical History of a Candle* is a book that cannot become old-fashioned; its way of teaching is so true and sure. Many a one who read Faraday's book when a boy has been grateful for a lifetime, for it makes clear the difference between knowledge that can be tested and mere hearsay, between knowledge that is exact and vague opinions, between knowledge that is clear and misty views. We do not mean that there is no other kind of knowledge except this scientific knowledge—Faraday never agreed to that—we mean that science is a verifiable, exact, clear kind of knowledge which is gained by such ways as Faraday illustrates in this simple *Chemical History of a Candle.* Those who like the book as much as we liked it more than forty years ago will be interested, we think, in a short account of Faraday's life and work, and this is the object of our introduction.

Michael Faraday was born at Newington, then a suburb of London, on 22nd September 1791, third child of a journeyman blacksmith, who had come

south from Yorkshire. From a common day-school Michael passed when he was thirteen to be errand boy to a bookseller. After a year he became an apprentice and began to read some of the books he helped to dust and bind. He became keen for knowledge, and it was a great event when his elder brother, who followed the father's craft, gave him a few shillings to pay for admission to a course of evening lectures on Natural Philosophy. For this meant meeting kindred spirits as well as making a serious start with science. Another event was that one of the bookseller's customers took the apprentice to hear some Royal Institution lectures by the famous chemist Sir Humphry Davy. The lectures were eagerly mastered. The volume of Faraday's careful notes is still preserved as a precious relic. It is interesting that Faraday heard these lectures in the very room in Albemarle Street where he afterwards discoursed on *The Chemical History of a Candle,* and on hundreds of other subjects. Going to Sir Humphry Davy's lectures was a turning-point in a curious way; the great chemist got his eye seriously injured in an explosion, and Faraday was somehow or other called in to write letters for him. When this short engagement came to an end, Faraday took "the bold and simple step" (as he called it) of writing to the great man, offering himself as an assistant. In Dr. J. H. Gladstone's *Michael Faraday* (1872) we read that Davy called with the letter on one of his friends, and said, "Pepys, what

am I to do? Here is a letter from a young man named Faraday; he has been attending my lectures, and wants me to give him employment at the Royal Institution—*what can I do?*" "Do?" replied Pepys; "put him to wash bottles: if he is good for anything, he will do it directly; if he refuses, he is good for nothing." "No, no," replied Davy, "we must try him with something better than that." And he did.

So in 1813 Faraday became assistant at the Royal Institution, and there he remained at work with ever-brightening fame for over fifty years. Soon after his appointment he had the interesting experience of travelling in Europe with Sir Humphry Davy for a year and a half. It was like a college course to Faraday. "But his University was Europe; his professors the master whom he served, and those illustrious men to whom the renown of Davy introduced the travellers." Returning to London, Faraday gave his first lecture and published his first paper, and then for years and years he continued assisting Davy, making chemical experiments, giving scientific advice, superintending laboratories, and discovering new knowledge. In 1821 he married, and brought his bride to rooms in the Royal Institution, where he spent most of the rest of his life.

"Up to 1833 Faraday was bringing the forces of nature in subjection to man on a salary of only £100 per annum, with house, coals, and candles, as the funds of the Institution would not at that

time afford more." He got another £100 by and by when an admirer founded for his benefit a Professorship of Chemistry. We wish to explain how Faraday lived in comfort and peace of mind when he was receiving so small an income, for the answer contains one of the side-lessons of his life. The fact is that he earned money readily by making chemical analyses for manufacturers and others, and in 1830 his gains from this source amounted to £1,000; next year they were still more; and they might have increased enormously without anything but credit. But in 1831 Faraday made one of his great discoveries as to the relationship between electricity and magnetism, and he determined to stop money-making and give his whole thought to Nature's secrets. Next year, we read, his outside earnings were reduced to £155 9s., and during no subsequent year did they amount to as much. It was quite characteristic of the man that he would not allow himself to be distracted from his high calling of discoverer.

"For year after year the life of Faraday afforded no adventure and little variety, only an ever-growing skill in his favourite pursuits, higher and higher success, and ever-widening fame." But we must not think of him as for ever like a stretched bow. He was fond of young folks and of good company; he enjoyed a country ramble and simple house-games; he often went with his wife and niece to the Zoological Gardens or to the theatre. He enjoyed

his life to the full, and the Sundays not least, for he was a deeply religious man. When his working days were over the Queen offered him (in 1858) a pretty little house at Hampton Court, and it was in quietness there that he spent the evening of his life. He died on 25th August 1867, one of the most distinguished of scientific investigators. "Altogether it appears that he was decorated with ninety-five titles and marks of merit, including the blue ribbon of science, for in 1844 he was chosen one of the eight foreign associates of the French Academy." For some reason he could never be induced to accept the highest British scientific honours, the presidentships of the Royal Society of London and of the British Association.

Faraday seems to have been lithe of body, very alert and buoyant, with gleaming kindly eyes, and a radiating vitality. In lecturing he was carried away by his subject, and he carried his audience with him in irresistible enthusiasm. There is little use trying to describe his mind, for he was by himself —a genius. He had, one may say, an unusual power of clear penetrating insight, which includes imagination. Without being trained in mathematics, he had the mathematician's vision. He had great ingenuity in devising experiments, and much of his thinking seems to have been an intensely rapid experimenting inside his head. When he got hold of a clue he followed it up with doggedness, but also with extraordinary quickness. Experts have

pointed with astonishment to the shortness of the time that often elapsed between Faraday's statement of a problem and his discovery of the answer. Speaking of his own work, Faraday said that he always needed to *see* things for himself before he gripped them in his mind. Even when he saw others make some new experiment he did not seem satisfied until he had repeated it himself. He was what is sometimes called " eye-minded." As he said himself: " I was never able to make a fact my own without *seeing* it."

Faraday's mind must have been a very wonderful activity, but he never spoke of his work as magical. To those who would learn he gives simple advice from his own experience. He tells us to get into the " habit of forming clear and precise ideas " and of expressing them in " clear and definite language." Clearness meant everything to Faraday. He tells us to balance one clear idea against another, not to hurry to a decision, not to allow our wishes to tamper with our thoughts, to be sure of facts but doubtful of theories. " The man who is certain he is right is almost sure to be wrong." " We may be *sure* of facts, but our interpretation of facts we should doubt." And another of his sentences runs: " For my part, I think that as facts are the foundation of science, however they may be interpreted, so they are most valuable, and often more so than the interpretations founded upon them." This reminds us of the interjection with which a great Scottish

theologian, Dr. Chalmers, used to stop wordy argument: "Give us a fact, man; give us a fact."

It may seem a little difficult at first sight, but there is something so very fine about a passage Faraday wrote when he was young, that we venture to quote it here. "The philosopher should be a man willing to listen to every suggestion, but determined to judge for himself. He should not be biassed by appearances, have no favourite hypothesis, be of no school, and in doctrine have no master. He should not be a respecter of persons, but of things. Truth should be his primary object. If to these qualities be added industry, he may indeed hope to walk within the veil of the temple of Nature." Faraday lived true to his youthful vision, and he is one of the Immortals. In a very clearly-written book, *Faraday as Discoverer* (1868), Professor Tyndall wrote: "Taking him for all and all, I think it will be conceded that Michael Faraday was the greatest experimental philosopher the world has ever seen; and I will add the opinion, that the progress of future research will tend, not to dim or to diminish, but to enhance and glorify the labours of this mighty investigator." We believe that the leading chemists and electricians of to-day would agree with Professor Tyndall's tribute.

It is interesting to get some details about his everyday ways in his laboratory, and some of them may be of use to us. He was, for instance, extraordinarily neat and tidy, insisting on having a place

for everything and on putting back everything he used into its place. In making an experiment he did not like to have things about that were not really needed and he was careful not to waste any energy. Like many very busy men, though not all, he was almost finnicking in his orderliness. Perhaps this had something to do with his habit of always picturing things in his head. Disorder was like a discord. Faraday had great skill with his hands, but it was characteristic of him that he always sought out the simplest possible appliances. Dr. Gladstone tells how Faraday went out with some others one night in the English Channel to study the lights of different lightships; the others had brought their best light-measurers or photometers; but the prince of investigators produced a lady's black shawl-pin and showed that it served admirably. "Steaming up the Thames one July day in a penny boat, he was struck with the offensiveness of the water. He tore some white cards into pieces, wetted them so as to make them sink easily, and dropped them into the river at each pier they came to. Their sudden disappearance from sight, though the sun was shining brightly, was proof enough of the impurity of the stream; and he wrote a letter to the *Times* describing his observations, and calling public attention to the dangerous state of the river." Dr. Gladstone recalls *Punch's* cartoon the following week which represented Professor Faraday holding his nose, and presenting his *card* to Father Thames,

who rises out of the unsavoury water. Faraday was one of the early advocates of more study of science in schools, but his recommendation that the appliances used should be kept very simple has been often forgotten.

It is not possible to make clear in a short time or without much study the great discoveries that Faraday made, but we wish to say three simple things. (1) There is a Greek fable about an "old man of the sea," called Proteus, who looked after Neptune's flocks of seals, and had the power of revealing the future to those who could catch him. But he was unwilling to prophesy and very difficult to catch, for he could change from shape to shape, at one time a whirlwind and at another time a flame, at one time a stream and at another time a dragon. Now Dr. Gladstone tells us, in the book we have already mentioned, that the favourite thought of Faraday seems to have been that the various forces of Nature were like the changing forms of a Proteus. In other words, Faraday greatly advanced the truth of the "transformations of energies," that the different kinds of power in the world change from form to form. Motion gives rise to heat and heat gives rise to light, and so the changes go. Nothing is ever lost, but the form changes. Especially important was Faraday's work on the relationship of electricity and magnetism, and on the relationship between these and light. (2) Faraday was the first to clear up what is called the induction of

electrical currents,—the fact that if an electrified body is brought near another body, with the invisible barrier of air between, the electrical state of the second body is changed. From this discovery a multitude of important consequences have flowed. (3) Always seeking to break down barriers and disclose the one-ness of things, Faraday was one of the pioneers in condensing gases into liquid and even into solid form, and this discovery also has borne much fruit. But we must be content with saying that few men of science have to their credit so many discoveries of the first rank of importance as Faraday has.

The great value of Faraday's work was in theoretical discovery, rather than in practical invention. He was more concerned with finding out what is true, than with making what is useful. But it was in the sunlight of Faraday's theoretical discoveries that many great practical inventions, like telegraphy, electric light, and wireless messages, blossomed. And it is very important that everyone should understand that *all* the ingenious practical inventions that have made modern life so different from that of past ages depend on theoretical discoveries made by patient experimenting and hard thinking. What has seemed at the time to impatient people like a waste of brains has often turned out to be of the highest practical importance. We do not mean, however, that Faraday, the discoverer, held himself aloof from practical applications. On the contrary he touched many

of them with his genius,—India-rubber, alloys of steel, patent locks, lamps, optical glass, electro-plating, mirrors, ventilation, artificial rubies, benzine, and a score of devices in which electro-magnetism is utilised. But we have to remember that what claimed Faraday's full strength was discovering the secrets of Nature, not using them. He liked to be called a "philosopher."

His character was marked by great kindliness, a genuine respect and love for his fellow men. Yet he did not suffer fools gladly and he was quick to take fire if he detected what seemed to him any lack of respect for truth or justice or the dignity of science. He had a joyous disposition and radiated good cheer. He seemed to get very close to Nature, and no doubt the depth of his knowledge made storms and sunsets, in which he delighted, more full of meaning to him than to ordinary men. He was not the cold man of science, for although he never allowed feeling to influence his scientific thinking, he could not conceal his enthusiasm in discovery or even in observation. He danced round the moving arches of light caused by an electric discharge in vacuum tubes, crying, "Oh, to live always in it." In a tremendous storm he was detected rubbing his hands with delight because he had seen the lightning strike the church tower. "A new fact," Dr. Gladstone tells us, "seemed to charge him with an energy that gleamed from his eyes and quivered through his limbs." Yet along with these high qualities

went more ordinary ones, such as patience and pertinacity. We like this little story: "Arranging some apparatus one day with a philosophical instrument maker, he let fall on the floor a small piece of glass: he made several ineffectual attempts to pick it up. "Never mind," said his companion, "it is not worth the trouble." "Well, but, Murray, I don't like to be beaten by something that I have once tried to do." We could not end our introduction on a firmer note than this, but there is another that is finer. According to Professor Tyndall, Faraday was "a man of excitable and fiery nature; but through high self-discipline he had converted the fire into a central glow and motive power of life, instead of permitting it to waste itself in useless passion." He had a good nature to start with and by ruling his spirit he made it better.

Coming back to chemistry, let us remember a favourite experiment of Faraday's, which, as Professor Tyndall says, was representative of the man himself. "He loved to show that water in crystallising excluded all foreign ingredients, however intimately they might be mixed with it. Out of acids, alkalis, or saline solutions, the crystal came sweet and pure. By some such natural process in the formation of this man, beauty and nobleness coalesced, to the exclusion of everything vulgar and low. He did not learn his gentleness in the world, for he withdrew himself from its culture; and still this land of England contained no truer gentleman than he."

FROM SIR WILLIAM CROOKES' INTRODUCTION TO THE FIRST EDITION

FROM the primitive pine-torch to the paraffin candle, how wide an interval! between them how vast a contrast! The means adopted by man to illuminate his home at night, stamp at once his position in the scale of civilisation. The fluid bitumen of the far East, blazing in rude vessels of baked earth; the Etruscan lamp, exquisite in form, yet ill adapted to its office; the whale, seal, or bear fat, filling the hut of the Esquimaux or Lap with odour rather than light; the huge wax candle on the glittering altar; the range of gas lamps in our streets,—all have their stories to tell. All, if they could speak (and, after their own manner, they can), might warm our hearts in telling how they have ministered to man's comfort, love of home, toil, and devotion.

Surely, among the millions of fire-worshippers and fire-users who have passed away in earlier ages, *some* have pondered over the mystery of fire; perhaps some clear minds have guessed shrewdly near the truth. Think of the time man has lived in hopeless ignorance: think that only during a period which might be spanned by the life of one man, has the truth been known.

Atom by atom, link by link, has the reasoning

chain been forged. Some links, too quickly and too slightly made, have given way, and been replaced by better work; but now the great phenomena are known—the outline is correctly and firmly drawn—cunning artists are filling in the rest, and the child who masters these Lectures knows more of fire than Aristotle did.

The candle itself is now made to light up the dark places of nature; the blowpipe and the prism are adding to our knowledge of the earth's crust; but the torch must come first.

Among the readers of this book some few may devote themselves to increasing the stores of knowledge: the Lamp of Science *must* burn.

W. CROOKES.

THE CHEMICAL HISTORY OF A CANDLE

1. Introduction

I PURPOSE to bring before you, in the course of these lectures, the Chemical History of a Candle. I have taken this subject on a former occasion; and, were it left to my own will, I should prefer to repeat it almost every year—so abundant is the interest that attaches itself to the subject, so wonderful are the varieties of outlet which it offers into the various departments of philosophy. There is not a law under which any part of this universe is governed which does not come into play, and is touched upon in these phenomena. There is no better, there is no more open door by which you can enter into the study of natural philosophy, than by considering the physical phenomena of a candle. I trust, therefore, I shall not disappoint you in choosing this for my subject rather than any newer topic, which could not be better, were it even so good.

2. What are Candles made of?

(*a*) *Wood.* Some candles are great curiosities. There is a very curious substance taken out of some of the bogs in Ireland, called *candle-wood*,—a hard,

strong, excellent wood, evidently fitted for good work as a resister of force, and yet withal burning so well that where it is found they make splinters of it, and torches, since it burns like a candle, and gives a very good light indeed. And in this wood we have one of the most beautiful illustrations of the general nature of a candle that I can possibly give. The fuel provided, the means of bringing that fuel to the place of chemical action, the regular and gradual supply of air to that place of action—heat and light—all produced by a little piece of wood of this kind, forming, in fact, a natural candle.

(*b*) *Tallow.* Here are a couple of candles commonly called dips. They are made of lengths of cotton cut off, hung up by a loop, dipped into melted tallow, taken out again and cooled, then re-dipped until there is an accumulation of tallow round the cotton. Dips were made in different sizes. Very small dips were formerly used by miners in coal mines. In olden times the miner had to find his own candles; and it was supposed that a small candle would not so soon set fire to the firedamp in the coal mines as a large one; and for that reason, as well as for economy's sake, he had candles made of this sort—20, 30, 40, or 60 to the pound. They have been replaced since then by the Davy-lamp, and other safety-lamps of various kinds.

(*c*) *Stearin.* Gay Lussac, or someone who entrusted him with his knowledge, converted the tallow em-

ployed in the manufacture of these dips, into this beautiful substance, stearin. A candle, you know, is not now a greasy thing like an ordinary tallow candle, but a clean thing, and you may almost scrape off and pulverise the drops which fall from it without soiling anything. This is the process he adopted:—The fat or tallow is first boiled with quicklime, and made into a soap, and then the soap is decomposed by sulphuric acid, which takes away the lime, and leaves the fat rearranged as stearic acid, whilst a quantity of glycerin is produced at the same time. Glycerin—absolutely a sugar, or a substance similar to sugar—comes out of the tallow in this chemical change. The oil is then pressed out of it; and as the pressure goes on increasing you have left that substance which is melted, and cast into candles.

The candle I have in my hand is a stearin candle, made of stearin from tallow in the way I have told you.

(*d*) *Other materials used.* Then here is a sperm candle, which comes from the purified oil of the spermaceti whale. Here also are yellow beeswax and refined beeswax, from which candles are made. Here, too, is that curious substance called paraffin, and some paraffin candles made of paraffin obtained from the bogs of Ireland.

3. The Manufacture of Candles

And how are these candles made? Let us imagine any of these candles to be made of materials which

can be cast. "Cast!" you say. "Why, a candle is a thing that melts; and surely if you can melt it, you can cast it." Not so. It is wonderful, in the progress of manufacture, and in the consideration of the means best fitted to produce the required result, how things turn up which one would not expect beforehand. Candles cannot always be cast. A wax candle can never be cast. It is made by a particular process which I can illustrate in a minute or two; but I must not spend much time on it. Wax is a thing which, burning so well, and melting so easily in a candle, cannot be cast. However, let us take a material that can be cast, say stearin. A frame is used with a number of moulds fastened in it. The first thing to be done is to put a wick through them. It goes to the bottom, where it is pegged in—the little peg holding the cotton tight, and stopping the aperture, so that nothing fluid shall run out. At the upper part there is a little bar placed across, which stretches the cotton and holds it in the mould. The tallow is then melted, and the moulds are filled. After a certain time, when the moulds are cool, the excess of tallow is poured off at one corner, and then cleaned off altogether, and the ends of the wick cut away. The candles alone then remain in the mould, and you have only to upset them, when out they tumble, for the candles are made in the form of cones, being narrower at the top than at the bottom; so that what with their form and their own shrinking, they only need a little shaking, and out they fall. It

is a curious thing to see how wax candles are made. A lot of cottons are hung upon frames, and covered with metal tags at the ends to keep the wax from covering the cotton in those places. These are carried to a heater, where the wax is melted. The frames can turn round; and as they turn, a man takes a vessel of wax, and pours it first down one, and then the next, and the next, and so on. When he has gone once round, if it is sufficiently cool, he gives the first a second coat, and so on until they are all of the required thickness. When they have been thus clothed, or fed, or made up to that thickness, they are taken off, and placed elsewhere. They are then well rolled upon a fine stone slab, and the conical top is moulded by properly shaped tubes, and the bottoms cut off and trimmed. This is done so beautifully that they can make candles in this way weighing exactly four, or six, to the pound, or any number they please.

4. The Candle Flame

We will light one or two, and set them at work in the performance of their proper functions. You observe a candle is a very different thing from a lamp. With a lamp you take a little oil, fill your vessel, put in a little moss or some cotton prepared by artificial means, and then light the top of the wick. When the flame runs down the cotton to the oil, it gets extinguished, but it goes on burning in the

BIBLIOTHEQUE
du
College Saint-Jean
Edmonton, Alberta

part above. Now, I have no doubt you will ask, how is it that the oil, which will not burn of itself, gets up to the top of the cotton, where it will burn? We shall presently examine that; but there is a much more wonderful thing about the burning of a candle than this. You have here a solid substance with no vessel to contain it; and how is it that this solid substance can get up to the place where the flame is? How is it that this solid gets there, it not being a fluid? or, when it is made a fluid, then how is it that it keeps together? This is a wonderful thing about a candle. Notice a candle which has been burning a little while.

(*a*) Observe that a beautiful cup is formed just under the flame. As the air comes to the candle it moves upward by the force of the current which the heat of the candle produces, and it so cools all the sides of the wax, tallow, or fuel, as to keep the edge much cooler than the part within; the part within melts by the flame that runs down the wick as far as it can go before it is extinguished, but the part on the outside does not melt. If I made a current in one direction, my cup would be lopsided, and the fluid would consequently run over,—for the same force of gravity which holds worlds together holds this fluid, in a horizontal position, and if the cup be not horizontal, of course the fluid will run away in guttering. You see, therefore, that the cup is formed by this beautifully regular ascending current of air playing upon all sides, which keeps

the exterior of the candle cool. No fuel would serve for a candle which has not the property of giving this cup, except such fuel as the Irish bogwood, where the material itself is like a sponge, and holds its own fuel. You readily see, therefore, that you would have a bad result if you were to burn those beautiful candles which are irregular, intermittent in their shape, and cannot therefore have that nicely formed edge to the cup which is the great beauty in a candle. I hope you will now see that the perfection of a process—that is, its utility—is the better point of beauty about it. It is not the best looking thing, but the best acting thing, which is the most advantageous to us. A good-looking candle is a bad burning one. There will be a guttering round about it because of the irregularity of the stream of air and the badness of the cup which is formed thereby. You may see some pretty examples (and I trust you will notice these instances) of the action of the ascending current when you have a little gutter running down the side of a candle, making it thicker there than it is elsewhere. As the candle goes on burning, this keeps its place and forms a little pillar sticking up by the side, because, as it rises higher above the rest of the wax or fuel, the air gets better round it, and it is more cooled and better able to resist the action of the heat at a little distance. Now, the greatest mistakes and faults with regard to candles, as in many other things, often bring with them instruction which we should not receive if they had not occurred.

We come here to be philosophers; and I hope you will always remember that whenever a result happens, especially if it be new, you should say, "What is the cause? Why does it occur?" and you will in the course of time find out the reason.

(*b*) Then the fluid in the cup rises up the wick, by capillary attraction, and into the place of combustion. You know that the candle flame does not run down to the wax or other matter, and melt it all away, but keeps to its own right place. It is fenced off from the fluid below, and does not encroach on the cup at the sides. I cannot imagine a more beautiful example than the condition of adjustment under which a candle makes one part subserve to the other to the very end of its action. A combustible thing like that, burning away gradually, never being intruded upon by the flame, is a very beautiful sight; especially when you come to learn what a vigorous thing flame is—what power it has of destroying the wax itself when it gets hold of it, and of disturbing its proper form if it come only too near.

But how does the flame get hold of the fuel? There is a beautiful point about that—*capillary attraction.* "Capillary attraction!" you say,—"the attraction of hairs." Well, never mind the name: it was given in old times, before we had a good understanding of what the real power was. It is by what is called capillary attraction that the fuel is conveyed to the part where combustion goes on,

and is deposited there, not in a careless way, but very beautifully in the very midst of the centre of action which takes place around it. Now, I am going to give you one or two instances of capillary attraction.

(1) It is that kind of action or attraction which makes two things that do not dissolve in each other still hold together. When you wash your hands,

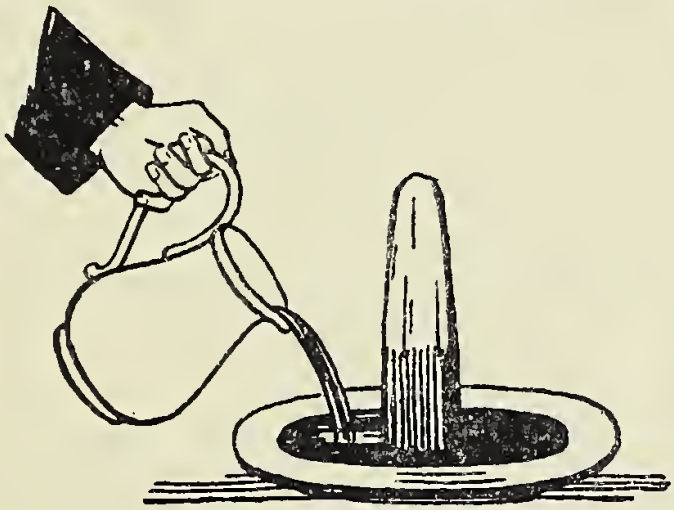


Fig. 1

you wet them thoroughly; you take a little soap to make the adhesion better, and you find your hand remains wet. This is by that kind of attraction of which I am about to speak. And, what is more, if your hands are not soiled (as they almost always are by the usages of life), if you put your finger into a little warm water, the water will creep a little way up the finger, though you may not stop to examine it.

(2) I have here a substance (Fig. 1) which is rather porous—a column of salt—and I will pour into the

plate at the bottom, not water, as it appears, but a saturated solution of salt which cannot absorb more; so that the action which you see will not be due to its dissolving anything. We may consider the plate to be the candle, and the salt the wick, and this solution the melted tallow. (I have coloured the fluid, that you may see the action better.) You observe that, now I pour in the fluid, it rises and gradually creeps up the salt higher and higher; and provided the column does not tumble over, it will go to the top. If this coloured solution were combustible, and we were to place a wick at the top of the salt, it would burn as it entered into the wick. It is a most curious thing to see this kind of action taking place, and to observe how singular some of the circumstances are about it.

(3) When you wash your hands, you take a towel to wipe off the water; and it is by that kind of wetting, or that kind of attraction which makes the towel become wet with water, that the wick is made wet with the tallow. I have known some careless boys and girls (indeed, I have known it happen to careful people as well) who, having washed their hands and wiped them with a towel, have thrown the towel over the side of the basin, and before long it has drawn all the water out of the basin and conveyed it to the floor, because it happened to be thrown over the side in such a way as to serve the purpose of a syphon. (See Fig. IA.)

(4) That you may better see the way in which

the substances act one upon another, I have here a vessel made of wire gauze filled with water, and you may compare it in its action to the cotton in one respect, or to a piece of calico in the other. In fact, wicks are sometimes made of a kind of wire gauze. You will observe that this vessel is a porous thing; for if I pour a little water on to the top, it will run

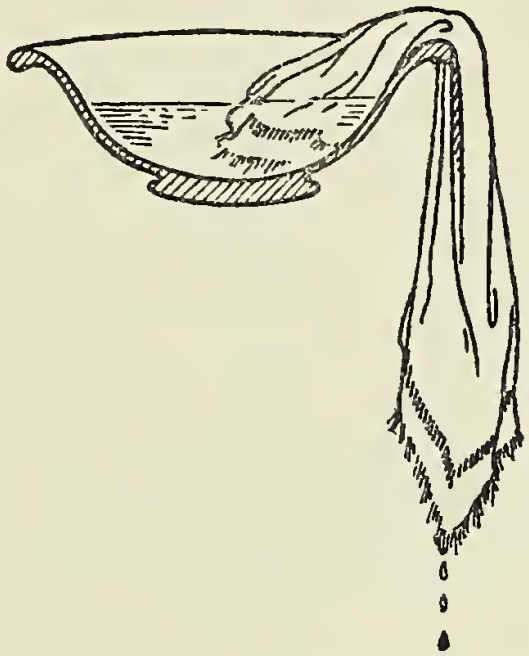


Fig. 1A

out at the bottom. You would be puzzled for a good while if I asked you what the state of this vessel is, what is inside it, and why it is there? The vessel is full of water, and yet you see the water goes in and runs out as if it were empty. In order to prove this to you, I have only to empty it. The reason is this,—the wire, being once wetted, remains wet; the meshes are so small that the fluid is attracted so strongly from the one side to the other, as to

remain in the vessel although it is porous. In like manner the particles of melted tallow ascend the cotton and get to the top; other particles then follow by their mutual attraction for each other, and as they reach the flame they are gradually burned.

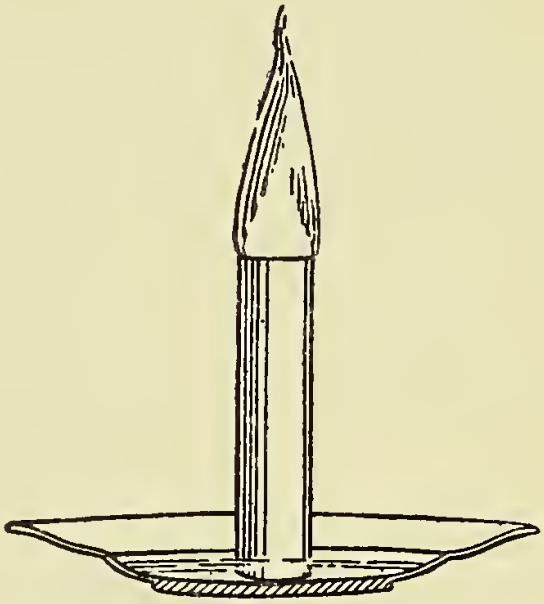


Fig. 1B

(5) Here is another application of the same principle. I have seen boys about the streets, who are very anxious to appear like men, take a piece of cane, and light it and smoke it, as an imitation of a cigar. They are enabled to do so by the permeability of the cane in one direction, and by its capillarity. If I place a piece of cane on a plate containing some camphine (which is very much like paraffin in its general character), exactly in the same manner as the coloured fluid rose through the salt will this

fluid rise through the piece of cane. There being no pores at the side, the fluid cannot go in that direction, but must pass through its length. Already the fluid is at the top of the cane: now I can light it and make it serve as a candle. The fluid has risen by the capillary attraction of the piece of cane, just as it does through the cotton in the candle. (Fig. 1B.)

(*c*) Further, the fuel must be in a vaporous condition before it will burn.

Now, the only reason why the candle does not burn all down the side of the wick is, that the melted tallow extinguishes the flame. You know that a candle, if turned upside down, so as to allow the fuel to run upon the wick, will be put out. The reason is, that the flame has not had time to make the fuel hot enough to burn, as it does above, where it is carried in small quantities into the wick, and has all the effect of the heat exercised upon it.

There is another condition which you must learn as regards the candle, without which you would not be able fully to understand the philosophy of it, and that is the vaporous condition of the fuel. In order that you may understand that, let me show you a very pretty, but very common-place experiment. If you blow a candle out cleverly, you will see the vapour rise from it. You have, I know, often smelt the vapour of a blown-out candle—and a very bad smell it is; but if you blow it out cleverly, you will be able to see pretty well the vapour into which this solid matter is transformed. I will blow

out one of these candles in such a way as not to disturb the air around it, by the continuing action of my breath; and now, if I hold a lighted taper two or three inches from the wick, you will observe a train of fire going through the air till it reaches the candle. I am obliged to be quick and ready,

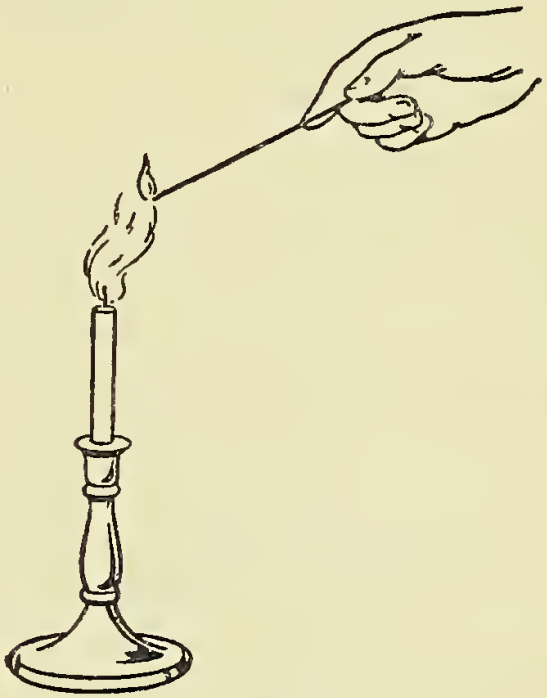


Fig. 2

because, if I allow the vapour time to cool, it becomes condensed into a liquid or solid, or the stream of combustible matter gets disturbed. (Fig. 2.)

(*d*) What determines the shape of the flame?

It concerns us much to know about the condition which the matter of the candle finally assumes at the top of the wick—where you have such beauty and brightness as nothing but combustion or flame can produce. You have the glittering beauty of gold

and silver, and the still higher lustre of jewels, like the ruby and diamond; but none of these rival the brilliancy and beauty of flame. What diamond can shine like flame? It owes its lustre at night-time to the very flame shining upon it. The flame shines in dark-

Fig. 3

ness, but the light which the diamond has is as nothing until the flame shines upon it, when it is brilliant again. The candle alone shines by itself, and for itself, or for those who have arranged the materials. Now, let us look a little at the form of the flame as you see it under a glass shade. It is steady and equal; and its general form varies with atmospheric disturbances, and according to the size of the candle.

It is a bright oblong—brighter at the top than towards the bottom—with the wick in the middle, and besides the wick in the middle, certain darker parts towards the bottom, where the ignition is not so perfect as in the part above. I have a drawing

Fig. 4

(Fig. 4), sketched many years ago by Hooker, when he made his investigations.

He has here represented the parts of the surrounding atmosphere that are very essential to the flame, and that are always present with it. There is a current formed, which draws the flame out—for the flame which you see is really drawn out by the current, and drawn upward to a great height.

You may see this by taking a lighted candle, and putting it in the sun so as to get its shadow thrown on a piece of paper. How remarkable it is that that thing which is light enough to produce shadows of other objects, can be made to throw its own shadow on a piece of white paper or card, so that you can actually see streaming round the flame something which is not part of the flame, but is ascending and drawing the flame upwards. Now, I am going to imitate the sunlight, by applying the voltaic battery to the electric lamp. You now see our sun, and its great luminosity; and by placing a candle between it and the screen, we get the shadow of the flame. You observe the shadow of the candle and of the wick; then there is a darkish part, as represented in the diagram, and then a part which is more distinct. Curiously enough, however, what we see in the shadow as the darkest part of the flame is, in reality, the brightest part; and here you see streaming upwards the ascending current of hot air, as shown by Hooker, which draws out the flame, supplies it with air, and cools the sides of the cup of melted fuel. (Figs. 3 and 4.)

I can give you here a little further illustration, for the purpose of showing you how flame goes up or down, according to the current. I have here a flame—it is not a candle flame—but you can, no doubt, by this time, generalise enough to be able to compare one thing with another. What I am about to do is to change the ascending current that takes

the flame upwards into a descending current. This I can easily do by the little apparatus you see before me. The flame, as I have said, is not a candle flame, but it is produced by alcohol, so that it shall not smoke too much. I will also colour the flame with a little chloride of copper, so that you may trace its

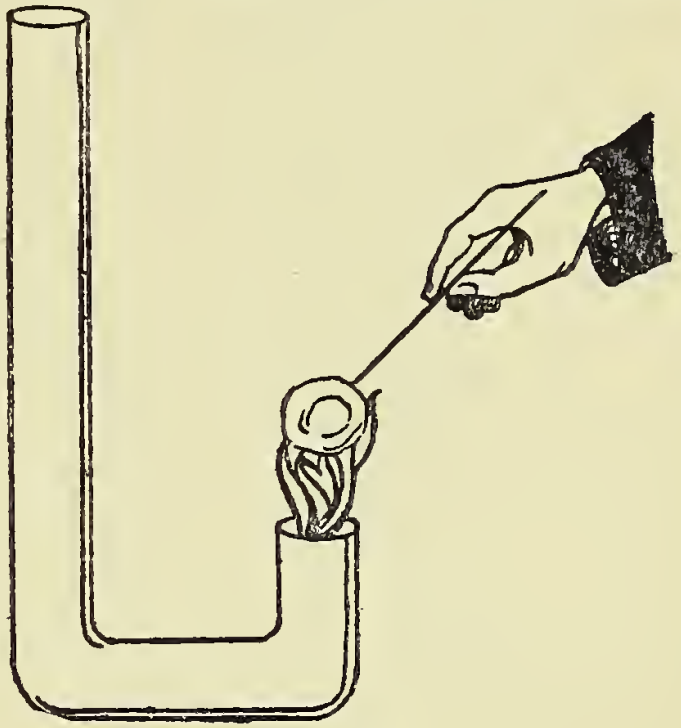


Fig. 5

course; for with the spirit alone you could hardly see well enough to have the opportunity of tracing its direction. By lighting this spirit-of-wine, we have then a flame produced; and, when held in the air, it naturally goes upwards. You understand now easily enough why flames go up under ordinary circumstances—it is because of the draught of air by which the combustion is formed. But now, by blowing the flame down, you see I am enabled to

make it go downwards into this little chimney—the direction of the current being changed. You see, then, that we have the power in this way of varying the flame in different directions.

There are now some other points that I must bring before you. Many of the flames you see vary very much in their shape by the currents of air blowing around them in different directions; but we can, if we like, make flames so that they will look like fixtures, and we can photograph them—indeed, we

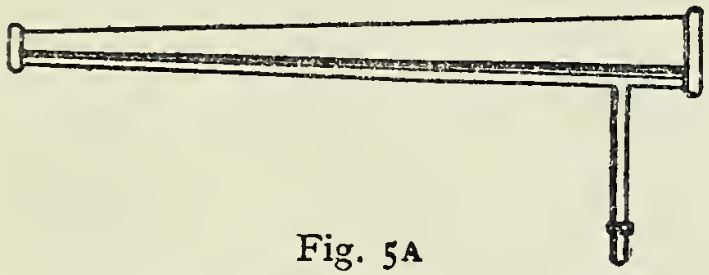


Fig. 5A

Blowpipe for changing direction of air current

have to photograph them—so that they become fixed to us, if we wish to find out everything concerning them. That, however, is not the only thing I wish to mention. If I take a flame sufficiently large, it does not keep that homogeneous, that uniform condition of shape, but it breaks out with a power of life which is quite wonderful. I am about to use another kind of fuel, but one which is truly and fairly a representative of the wax or tallow of a candle. I have here a large ball of cotton, which will serve as a wick. And, now that I have immersed it in spirit and applied a light to it, in what way does

it differ from an ordinary candle? Why, it differs very much in one respect, that we have a vivacity and power about it, a beauty and a life entirely different from the light presented by a candle. You see those fine tongues of flame rising up. You have the same general disposition of the mass of the flame from below upwards; but, in addition to that,

Fig. 6

you have this remarkable breaking out into tongues which you do not perceive in the case of a candle. (Fig. 6.) Now, why is this? I must explain it to you, because when you understand that perfectly, you will be able to follow me better in what I have to say hereafter. I suppose some here will have made for themselves the experiment I am going to show you. Am I right in supposing that anybody here has played at snapdragon? I do not know a more beautiful illustration of the philosophy of

flame, as to a certain part of its history, than the game of snapdragon. First, there is the dish; and let me say, that when you play snapdragon properly, you ought to have the dish well-warmed; you ought also to have warm plums and warm brandy.

When you have put the spirit into the dish, you have the cup and the fuel; and are not the raisins acting like the wicks? Now throw the plums into the dish, and light the spirit, and you see those beautiful tongues of flame that I refer to. You have the air creeping in over the edge of the dish forming these tongues. Why? Because, through the force of the current and the irregularity of the action of the flame, it cannot flow in one uniform stream. The air flows in so irregularly that you have what would otherwise be a single image, broken up into a variety of forms, and each of these little tongues has an independent existence of its own. Indeed, I might say, you have here a multitude of independent candles. You must not imagine, because you see these tongues all at once, that the flame is of this particular shape. A flame of that shape is never so at any one time. Never is a body of flame, like that which you just saw rising from the ball, of the shape it appears to you. It consists of a multitude of different shapes, succeeding each other so fast that the eye is only able to take cognisance of them all at once. They do not occur all at once: it is only because we see these shapes in such rapid succession, that they seem to us to exist all at one time.

5. The Zones of a Candle Flame

And now, I have to ask your attention to the means by which we are enabled to ascertain what happens in any particular part of the flame—why it happens, what it does in happening, and where, after all, the whole candle goes to: because, as you know very well, a candle being brought before us and burned, disappears, if burned properly, without the least trace of dirt in the candlestick—and this is a very curious circumstance. Here is a candle. You see the flame consists of two distinct parts or zones—the central part which is dark and can be seen at any time, if you look at a candle carefully, without blowing it about; and the outer part of the flame, which is very bright or luminous and readily seen.

(*a*) We will examine the dark part first.

Now, I take a bent glass tube, and introduce one end into that part of the flame, and you see at once that something is coming from the flame, out at the other end of the tube; and if I put a flask there, and leave it for a little while, you will see that something from the middle part of the flame is gradually drawn out, and goes through the tube and into that flask, and there behaves very differently from what it does in the open air. It not only escapes from the end of the tube, but falls down to the bottom of the flask like a heavy substance, as indeed it is. (Fig. 7.)

We find that this is the wax of the candle made into a vaporous fluid—not a gas. (You must learn the difference between a gas and a vapour: a gas remains permanent, a vapour is something that will condense.) If you blow out a candle, you perceive a very nasty

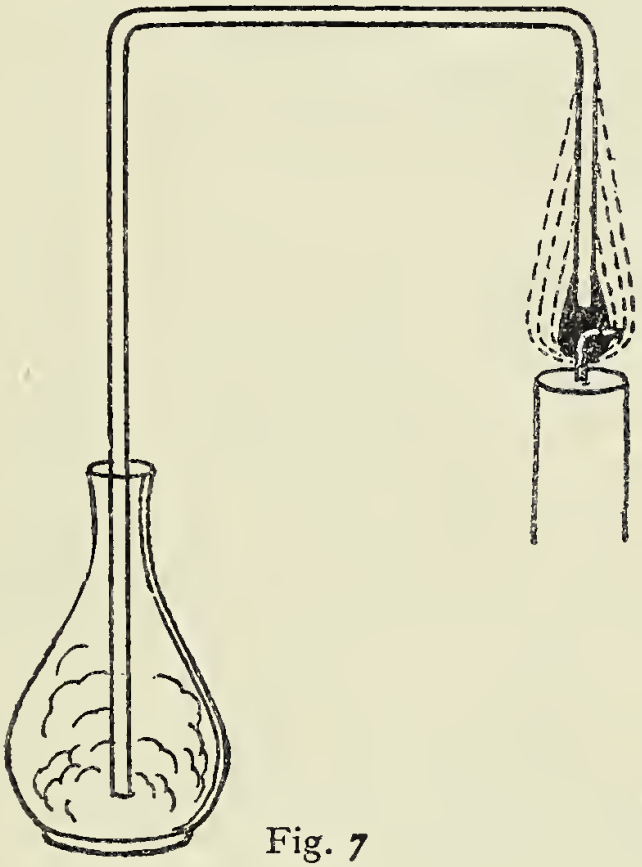


Fig. 7

smell, resulting from the condensation of this vapour. That is very different from what you have outside the flame; and, in order to make that more clear to you, I am about to produce and set fire to a larger portion of this vapour—for what we have in the small way in a candle, to understand thoroughly, we must, as philosophers, produce in a larger way, if

needful, that we may examine the different parts. Here is some wax is a glass flask, and I am going to make it hot, as the inside of that candle-flame is hot, and the matter about the wick is hot. You see that the wax I put in it has become fluid, and there is a little smoke coming from it. We shall very soon have the vapour rising up. I will make it still hotter, and now we get more of it, so that I can actually pour the vapour out of the flask into that basin, and set it on fire there. This, then, is exactly the same kind of vapour as we have in the middle of the candle; and that you may be sure this is the case, let us try whether we have not got here, in this flask (Fig. 7), a real combustible vapour out of the middle of the candle. See how it burns. Now, this is the vapour from the middle of the candle, produced by its own heat; and that is one of the first things you have to consider with respect to the progress of the wax in the course of its combustion, and as regards the changes it undergoes. I will arrange another tube carefully in the flame, and I should not wonder if we were able, by a little care, to get that vapour to pass through the tube to the other extremity, where we will light it, and obtain absolutely the flame of the candle at a place distant from it. Now, look at that. (Fig. 8.) Is not that a very pretty experiment? Talk about laying on gas—why, we can actually lay on a candle! And you see from this that there are clearly two different kinds of action—one the *production* of the vapour, and the

other the *combustion* of it—both of which take place in particular parts of the candle.

(*b*) Very briefly let us examine the outer or luminous part of the candle flame. If I raise the tube to the upper part of the flame, what comes away will be no longer combustible: it is already burned. How burned? Why, burned thus:—In the middle of the

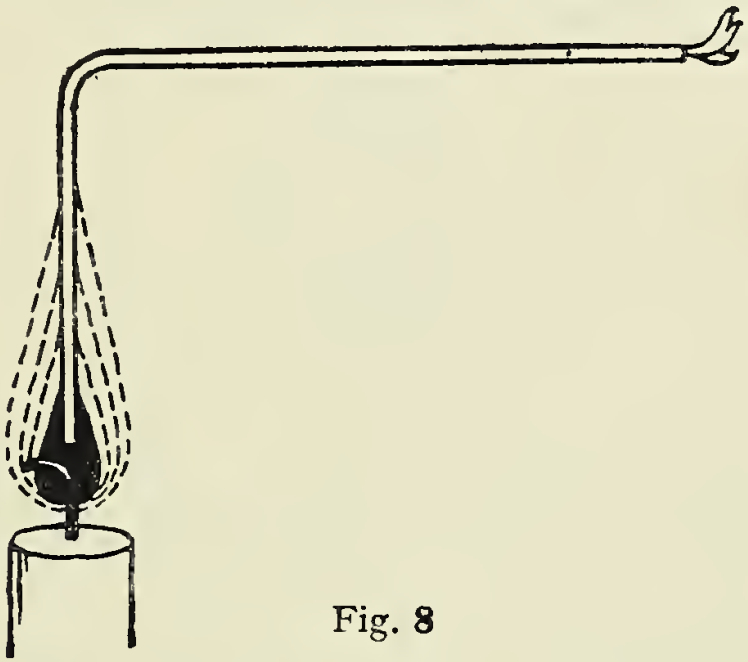


Fig. 8

flame, where the wick is, there is this combustible vapour; on the outside of the flame is the air which we shall find necessary for the burning of the candle; between the two, intense chemical action takes place, whereby the air and the fuel act upon each other, and at the very same time that we obtain light the vapour inside is destroyed. If you examine where the heat of a candle is, you will find it very curiously arranged. Suppose I hold a piece of paper close upon the flame, where is the heat of that flame? Do

you not see that it is *not* in the inside? It is in a ring, exactly in the place where I told you the chemical action was; and even in my irregular mode of making the experiment, if there is not too much disturbance, there will always be a ring. This is a good experiment for you to make at home. Take a strip of paper, have the air in the room quiet, and put the piece of

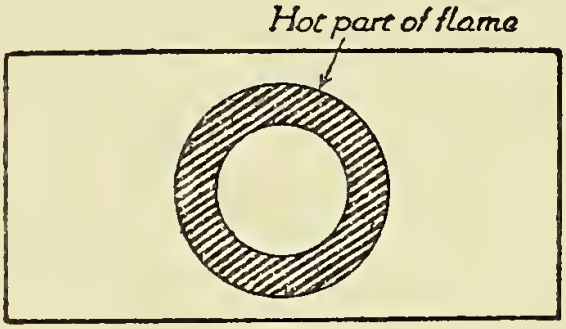


Fig. 8A

paper right across the middle of the flame, and you will find that it is burnt in this ring and that it is not burnt, or very little so, in the middle; and when you have tried the experiment once or twice, so as to make it nicely, you will be very interested to see where the heat is, and to find that it is where the air and the fuel come together.

6. Fresh Air is Necessary for Combustion

Air is absolutely necessary for combustion; and, what is more, I must have you understand that *fresh* air is necessary, or else we should be imperfect in our reasoning and our experiments. Here is a jar

of air. I place it over a candle, which burns very nicely in it at first, showing that what I have said about it is true; but there will soon be a change. See how the flame is drawing upwards, presently fading, and at last going out. And going out, why? Not because it wants air merely, for the jar is as full now as it was before; but it wants pure, fresh air. The jar is full of air, partly changed, partly not changed; but it does not contain sufficient of the fresh air which is necessary for the combustion of a candle. These are all points which we, as young chemists, have to gather up; and if we look a little more closely into this kind of action, we shall find certain steps of reasoning extremely interesting. For instance, here is an oil-lamp—an excellent lamp for our experiments—the old Argand lamp. It has a hollow, circular wick to permit the passage of air inside and outside the flame. I will cut off the flow of air into the centre of the flame and make it like a candle. There is the cotton; there is the oil rising up it; and there is the conical flame. It burns poorly, because there is a partial restraint of air. I have allowed no air to get to it, save round the outside of the flame, and it does not burn well. I cannot admit more air from the outside, because the wick is large; but if, as Argand did so cleverly, I open a passage to the middle of the flame, and so let air come in there, you will see how much more beautifully it burns. If I shut the air off, look how it smokes; and why? We have now some very

interesting points to study. We have the case of the combustion of a candle; we have the case of a candle being put out by the want of air; and we have now the case of imperfect combustion; and this is to us so interesting, that I want you to understand it as thoroughly as you do the case of a candle burning in its best possible manner. I will now make a great flame, by setting fire to this ball of cotton which has been steeped in turpentine. The cotton ball is really a very large wick. All these things are the same as candles, after all. If we have larger wicks, we must have a larger supply of air, or we shall have less perfect combustion. Look now at this black substance going up into the atmosphere; there is a regular stream of it. Look at the soots that fly off from the flame: see what an imperfect combustion it is, because it cannot get enough air. What, then, is happening? Why, certain things which are necessary to the combustion of a candle are absent, and very bad results are accordingly produced; but we see what happens to a candle when it is burnt in a pure and proper state of air.

7. Is Combustion always Accompanied by Flame?

But, though I take a candle and give you, as the general result, its combustion in the form of a flame, we must see whether combustion is always in this

condition, or whether there are other conditions of flame; and we shall soon discover that there are, and that they are most important to us. I think, perhaps, the best illustration of such a point to us, as juveniles, is to show the result of strong contrast. Here is a little gunpowder. You know that gunpowder burns with flame—we may fairly call it flame. It contains carbon and other materials, which all together cause it to burn with a flame. And here is some pulverised iron, or iron-filings. Now, I purpose burning these two things together. (Before I go into these experiments, let me hope that none of you, by trying to repeat them, for fun's sake, will do any harm. These things may all be very properly used if you take care; but without that, much mischief will be done.) I have a little mortar in which I will mix them, my object being to make the gunpowder set fire to the filings and burn them in the air, and thereby show the difference between substances burning with flame and not with flame. Here is the mixture; I will now set fire to it. You see the gunpowder burning with a flame; but the filings burn without the production of a flame. You see, then, these two great distinctions; and upon these differences depend all the utility and all the beauty of flame which we use for the purpose of giving out light. When we use oil, or gas, or candle, for the purpose of illumination, their fitness all depends upon these different kinds of combustion.

8. The Luminosity of a Flame
What is it due to?

Suppose I take a candle, and examine that part of it which appears brightest to our eyes. I will take this candle and clear away the gutterage, which occurs by reason of the currents of air; and if I now arrange a glass tube so as to dip into this luminous part, as in Figs. 7 and 8, only higher, you see the result. In place of having the same white vapour that you had before, you will now have a black vapour. There it goes, as black as ink. It is certainly very different from the white vapour; and when we put a light to it, we shall find that it does not burn, but that it puts the lights out. Well, these particles, as I said before, are just the smoke of the candle. But what is that black substance? Why, it is the same carbon which exists in the candle. How comes it out of the candle? It evidently existed in the candle, or else we should not have had it here. And now I want you to follow me in this explanation. You would hardly think that all those substances which fly about London, in the form of soots and blacks, are the very beauty and life of the flame, and which are burned in it as those iron-filings were burned here. Here is a piece of wire gauze, which will not let the flame go through it; and I think you will see, almost immediately, that when I bring it low enough to touch

that part of the flame which is otherwise so bright, that it quells and quenches it at once, and allows a volume of smoke to rise up.

I want you now to follow me in this point—that whenever a substance burns, as the iron-filings burnt in the flame of gunpowder, without assuming the vaporous state (whether it becomes liquid or remains solid), it becomes exceedingly luminous. I have here taken three or four examples apart from the candle, on purpose to illustrate this point to you; because what I have to say is applicable to all substances, whether they burn or whether they do not burn—that they are exceedingly bright if they retain their solid state, and that *it is to this presence of solid particles in the candle-flame that it owes its brilliancy.*

Here is a platinum-wire, a body which does not change by heat. If I heat it in this flame, see how exceedingly luminous it becomes. I will make the flame dim, for the purpose of giving a little light only, and yet you will see that the heat which it can give to that platinum-wire, though far less than the heat it has itself, is able to raise the platinum-wire to a far higher state of effulgence. This flame has carbon in it; but I will take one that has no carbon in it. There is a material, a kind of fuel—a vapour, or gas, whichever you like to call it—in that vessel, and it has no solid particles in it; so I take that because it is an example of flame itself burning without any solid matter whatever; and if

I now put this solid substance in it, you see what an intense heat it has, and how brightly it causes the solid body to glow. This is the pipe through which we convey this particular gas, which we call hydrogen, and which you shall know all about next time we meet. And here is a substance called oxygen, by means of which this hydrogen can burn; and although we produce, by their mixture, far greater heat than you can obtain from the candle, yet there is very little light. If, however, I take a solid substance, and put that into it, we produce an intense light. If I take a piece of lime, a substance which will not burn, and which will not vaporise by the heat (and because it does not vaporise, remains solid, and remains heated), you will soon observe what happens as to its glowing. I have here a most intense heat, produced by the burning of hydrogen in contact with the oxygen; but there is as yet very little light—not for want of heat, but for want of particles which can retain their solid state; but when I hold this piece of lime in the flame of the hydrogen as it burns in the oxygen, see how it glows! This is the glorious limelight, which rivals the voltaic-light, and which is almost equal to sunlight. I will hold a piece of carbon or charcoal in the flame: you see it burns and gives us light exactly in the same manner as if it were burnt as part of a candle. The heat that is in the flame of the candle decomposes the vapour of the wax, and sets free the carbon particles—they rise up heated and glowing as this now

glows, and then enter into the air. But the particles when burnt never pass off from a candle in the form of carbon. They go off into the air as a perfectly invisible substance, about which we shall know hereafter.

Is it not beautiful to think that such a process is going on, and that such a dirty thing as charcoal can become so incandescent? You see it comes to this—that all bright flames contain these solid particles; all things that burn and produce solid particles, either during the time they are burning, as in the candle, or immediately after being burnt, as in the case of the gunpowder and iron-filings,—all these things give us this glorious and beautiful light.

I will give you a few illustrations. Here is a piece of phosphorus, which burns with a bright flame. Very well; we may now conclude that phosphorus will produce, either at the moment that it is burning or afterwards, these solid particles. Here is the phosphorus lighted, and I cover it over with this glass for the purpose of keeping in what is produced. What is all that smoke? That smoke consists of those very particles which are produced by the combustion of the phosphorus. (Fig. 9.)

I have here a very hot crucible. I am about to throw into it some zinc-filings, and they will burn with a flame like gunpowder. I make this experiment because you can make it well at home. Now, I want you to see what will be the result of the

combustion of this zinc. Here it is burning—burning beautifully like a candle, I may say. But what is all that smoke, and what are those little clouds of wool which will come to you if you cannot come to them, and make themselves sensible to you in the form of the old philosophic wool, as it was called?

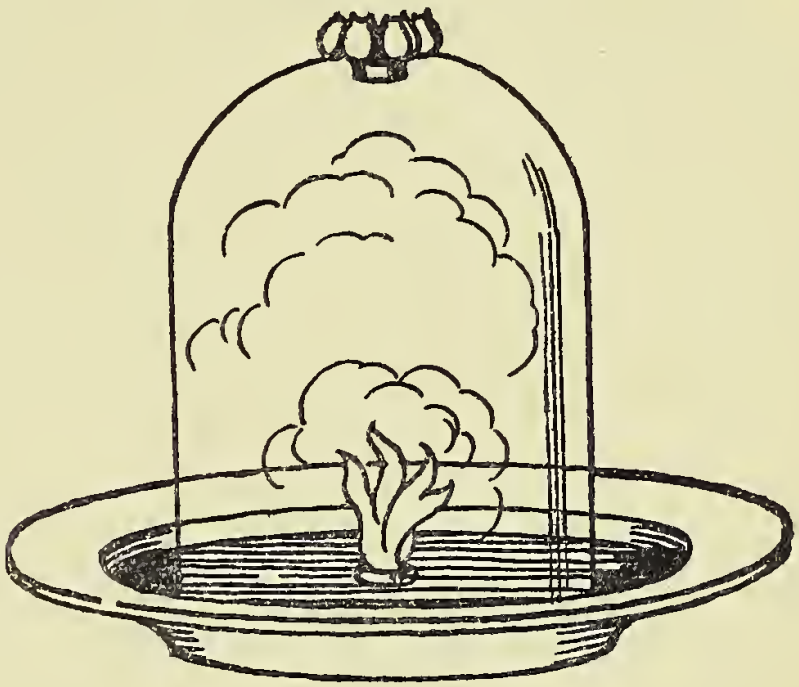


Fig. 9

We shall have left in that crucible, also, a quantity of this woolly matter. But I will take a piece of this same zinc and make an experiment a little more closely at home, as it were. I will try to burn it in a jet of hydrogen. It glows, you see: there is the combustion, and there is the white substance into which it burns. And so, if I take that flame of hydrogen as the representative of a candle, and show you a substance like zinc burning in the flames,

you will see that it was merely during the action of combustion that this substance glowed—while it was kept hot; and if I take a flame of hydrogen, and put this white substance from the zinc into it, look how beautifully it glows, and just because it is a solid substance.

I will now take such a flame as I had a moment since, and set free from it the particles of carbon. Here is some camphine, which will burn with a smoke; but if I send these particles of smoke through a pipe into the hydrogen flame, you will see they will burn and become luminous, because we heat them a second time. There they are. Those are the particles of carbon re-ignited a second time. They are those particles which you can easily see by holding a piece of paper behind them, and which, whilst they are in the flame, are ignited by the heat produced, and, when so ignited, produce this brightness. When the particles are not separated, you get no brightness. The flame of coal-gas owes its brightness to the separation, during combustion, of these particles of carbon, which are equally in that as in a candle. I can very quickly alter that arrangement. Here, for instance, is a bright flame of gas. Supposing I add so much air to the flame as to cause it all to burn before those particles are set free, I shall not have this brightness; and I can do that in this way:—If I place over the jet a wire-gauze cap, and then light the gas over it, it burns with a non-luminous flame, owing to its having plenty of air mixed with

it before it burns; and if I raise the gauze, it does not burn below. There is plenty of carbon in the gas; but, because the atmosphere can get to it, and mix with it before it burns, you see how pale and blue the flame is. And if I blow upon a bright gas-flame, so as to consume all this carbon before it gets heated to the glowing point, it will also burn blue. The only reason why I have not the same bright light when I thus blow upon the flame is, that the carbon meets with sufficient air to burn it before it gets separated in the flame in a free state. The difference is solely due to the solid particles not being separated before the gas is burnt.

9. The Products of Combustion of a Candle

You observe that there are certain products as the result of the combustion of a candle, and that of these products one portion may be considered as charcoal, or soot; that charcoal, when afterwards burnt, produces some other product; and it concerns us very much now to ascertain what that other product is. We showed that something was going away; and I want you now to understand how much is going up into the air; and for that purpose we will have combustion on a little larger scale. From that candle ascends heated air, and two or

three experiments will show you the ascending current; but, in order to give you a notion of the

Fig. 10

quantity of matter which ascends in this way, I will make an experiment by which I shall try to imprison some of the products of this combustion.

For this purpose I have here what boys call a fire-balloon. (Fig. 10.) I use this fire-ballon merely as a sort of measure of the result of the combustion we are considering; and I am about to make a flame in such an easy and simple manner as shall best serve my present purpose. This plate shall be the "cup," we will so say, of the candle; spirit shall be our fuel; and I am about to place this chimney over it, because it is better for me to do so than to let things proceed at random. I will now light the fuel, and here at the top we shall get the results of the combustion. What we get at the top of that tube is exactly the same, generally speaking, as you get from the combustion of a candle; but we do not get a luminous flame here, because we use a substance which is feeble in carbon. As soon as I put the balloon into position it commences to fill with the products of combustion. Does not that show you what a large volume of gaseous matter is being evolved?

Suppose I take another candle, and place it under a jar, and then put a light on the other side, just to show you what is going on. You see that the sides of the jar become cloudy, and the light begins to burn feebly. It is the products, you see, which make the light so dim, and this is the same thing which makes the sides of the jar so opaque. If you go home and take a spoon that has been in the cold air, and hold it over a candle—not so as to soot it—you will find that it becomes dim, just as that jar did. It is water which causes this dimness and, shortly, I

will try to prove to your satisfaction that this liquid is really water.

Before I do so let me tell you how to condense this liquid in quantities large enough to experiment

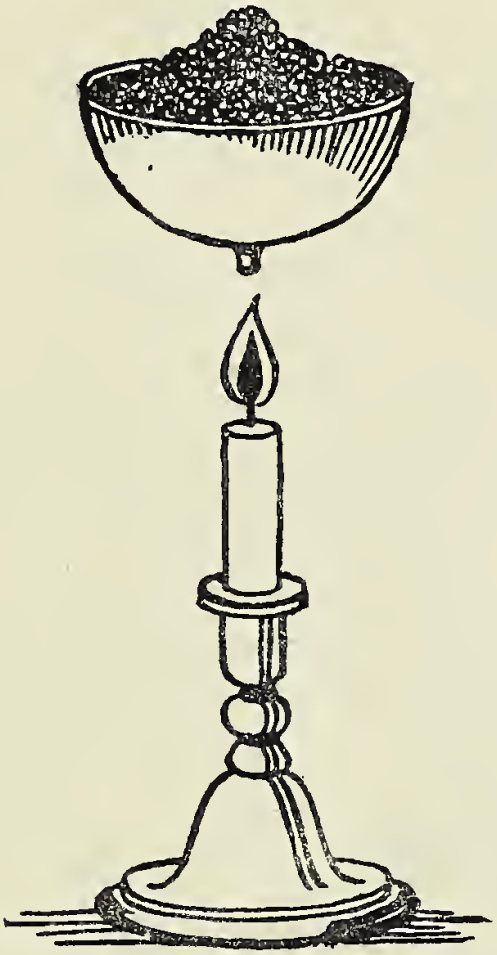


Fig. 11

with. I shall use an evaporating dish containing a mixture of ice and salt. This is a very cold mixture (it is called a "freezing" mixture) and will readily condense water vapour to the liquid state. I now place a candle underneath this dish and soon you will notice the appearance of a drop of water on the

outside of the dish. (Fig. 11.) I must carefully transfer the drops formed to another vessel, or else I shall be unable to fulfil the promise I made to you a little while ago: that is, prove that this liquid is water. (You could also use the apparatus shown in Fig. 18.)

Perhaps one of the best means that I can adopt to recognize this liquid is to exhibit a very visible action of water, and then to apply that test to the drops we have collected. I have here a chemical substance, discovered by Sir Humphry Davy, which has a very energetic action upon water, which I shall use as a test of the presence of water. If I take a little piece of it—it is called potassium, as coming from potash,—if I take a little piece of it, and throw it into a basin of water it shows the presence of water by lighting up and floating about, burning with a violet flame.

I will repeat this test with the liquid we have collected. I think I can show you that potassium has the same action upon it as upon the water in that basin in the experiment we have just tried. See, it takes fire, and burns in just the same manner. I will take another drop upon this glass slab, and when I put the potassium on to it, you see at once, from its taking fire, that there is water present. Now, that water was produced by the candle. I will put a spirit-lamp under a jar, and you will soon see the latter become damp, from the dew which is deposited upon it—that dew being the result of com-

bustion; and I have no doubt you will shortly see by the drops of water which fall upon the paper below, that there is a good deal of water produced from the combustion of the lamp. I will let it remain, and you can afterwards see how much water has been collected. So, if I take a gas-lamp, and put any cooling arrangement over it, I shall get water —water being likewise produced from the combustion of gas. Here, in this bottle, is a quantity of water —perfectly pure, distilled water, produced from the combustion of a gas-lamp—in no point different from the water that you distil from the river, or ocean, or spring, but exactly the same thing. Water is one individual thing—it never changes. We can add to it by careful adjustment, for a little while, or we can take it apart, and get other things from it; but water, as water, remains always the same, either in a solid, liquid, or fluid state. Here, I have some water produced by the combustion of an oil lamp. A pint of oil, when burnt fairly and properly, produces rather more than a pint of water. And so we can go on with almost all combustible substances, and find that if they burn with a flame, as a candle, they produce water. You may make these experiments yourselves. The head of a poker is a very good thing to try with, and if it remains cold long enough over the candle, you may get water condensed in drops on it; or a spoon or ladle, or anything else may be used, provided it be clean, and can carry off the heat and so condense the water.

10. Water Exists in the Solid, Liquid, and Gaseous States

And now—to go into the history of this wonderful production of water from combustibles, and by combustion—I must first of all tell you that this water may exist in different conditions; and although you may now be acquainted with all its forms, they still require us to give a little attention to them for the present, so that we may perceive how the water, whilst it goes through its Protean changes, is entirely and absolutely the same thing, whether it is produced from a candle, by combustion, or from the rivers or ocean.

First of all, water, when at the coldest, is ice. Now, we philosophers—I hope that I may class you and myself together in this case—speak of water as water, whether it be in its solid, or liquid, or gaseous state,—we speak of it chemically as water. Water is a thing compounded of two substances, one of which we have derived from the candle, and the other we shall find elsewhere. Water may occur as ice; and you have had most excellent opportunities of seeing this. Ice changes back into water—when the temperature is raised: water also changes into steam when it is warmed enough. The water which we have here before us is in its densest state, and although it changes in weight, in condition, in form, and in many other qualities, it still is water; and

whether we alter it into ice by cooling, or whether we change it into steam by heat, it increases in volume —in the one case very strangely and powerfully, and in the other case very largely and wonderfully.

Let us take the case of water changing into ice: we can effect that by cooling it in a mixture of salt and pounded ice; and I shall do so to show you the expansion of water into a thing of larger bulk when it is so changed. I have here some bottles which are made of strong cast iron, very strong and very thick—I suppose they are the third of an inch in thickness; they are very carefully filled with water so as to exclude all air, and then they are screwed down tight. We shall see that when we freeze the water in these iron vessels, they will not be able to hold the ice, and the expansion within them will break them in pieces.

I am about to put two bottles into a mixture of ice and salt, for the purpose of showing that when water becomes ice, it changes in volume in this extraordinary way. No communication can take place between the water in the bottles and the ice in the outer vessel. But there will be a conveyance of heat from the one to the other; and if we are successful, I expect you will by-and-by, so soon as the cold has taken possession of the bottles and their contents, hear a pop on the occasion of the bursting of the one bottle or the other; and, when we come to examine the bottles, we shall find their contents masses of ice, partly enclosed by the

covering of iron which is too small for them, because the ice is larger in bulk than the water. You know very well that ice floats upon water: if a boy falls through a hole into the water, he tries to get on the ice again to float him up. Why does the ice float?—think of that, and philosophise. Because the ice is larger than the quantity of water which can produce it; and therefore the ice weighs the lighter, and the water is the heavier. Ah! There is one of our bottles burst, and here you see is a crack down one side an eighth of an inch in width. This other bottle is also broken; although the iron was nearly half-an-inch thick, the ice has burst it asunder. These changes always take place in water: they do not require to be always produced by artificial means—we only use them here because we want to produce a small winter round that little bottle, instead of a long and severe one. But if you go to Canada, or to the North, you will find the temperature there out of doors will do the same thing as has been done here by the freezing mixture.

Fig. 11A

I will now take a tin cylinder (Fig. 12), and pour a little water into it; and seeing how much water I pour in, you may easily estimate for yourselves how high it will rise in the vessel: it will cover the bottom about two inches. I am now about to convert the water into steam, for the purpose of shewing to you the different volumes which water occupies

in its different states of water and steam. Look at the change which has taken place in the water to which we have applied heat—it is losing its fluid state. You may tell this by two or three circumstances. I have covered the mouth of this glass flask, in which water is boiling, with a watch-glass.

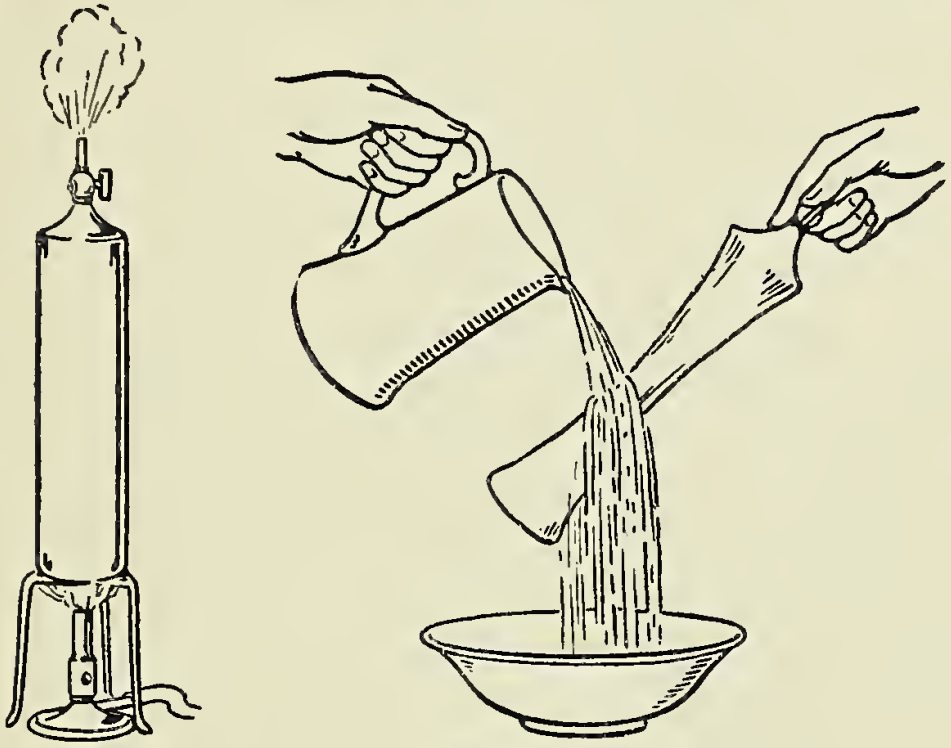


Fig. 12

Do you see what happens? It rattles away like a valve chattering, because the steam rising from the boiling water sends the valve up and down, and forces itself out, and so makes it clatter. You can very easily perceive that the flask is quite full of steam, or else it would not force its way out. You see, also, that the flask contains a substance very much larger than the water, for it fills the whole of

the flask over and over again, and there it is blowing away into the air; and yet you cannot observe any great diminution in the bulk of the water, which shows you that its change of bulk is very great when it becomes steam. See what a stream of vapour is issuing from this tin vessel! You observe, we must have made it quite full of steam to have it sent out in that great quantity. And now, as we can convert the water into steam by heat, we convert it back into liquid water by the application of cold. And if we take a glass, or any other cold thing, and hold it over this steam, see how soon it gets damp with water; it will condense it until the glass is warm—it condenses the water which is now running down the sides of it. I have here another experiment to show the condensation of water from a vaporous state back into a liquid state, in the same way as the vapour, one of the products of the candle, was condensed against the bottom of the dish, and obtained in the form of water; and to shew you how truly and thoroughly these changes take place, I will take this tin flask, which is now full of steam, and close the top. We shall see what takes place when we cause this water or steam to return back to the fluid state by pouring some cold water on the outside. You see what has happened. If I had closed the stopper, and still kept the heat applied to it, it would have burst the vessel; yet, when the steam returns to the state of water, the vessel collapses, there being a vacuum produced inside by the con-

densation of the steam. (Fig. 12.) I show you these experiments for the purpose of pointing out that in all these occurrences there is nothing that changes the water into any other thing—it still remains water; and so the vessel is obliged to give way, and is crushed inwards, as in the other case, by the further application of heat, it would have been blown outwards.

And what do you think the bulk of that water is when it assumes the vaporous condition? In Fig. 13 two cubes have been drawn, the larger one to represent a cubic foot and the smaller one to represent a cubic inch. Well, one cubic inch of water is sufficient to expand into a *cubic foot* of steam; and, on the contrary, the application of cold will contract that large quantity of steam into this small quantity of water.

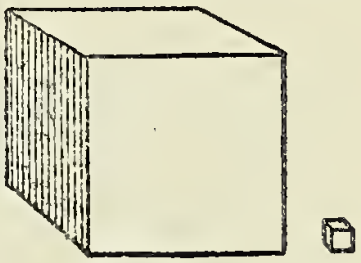


Fig. 13

To return to our quiet philosophy. We shall not in future be deceived, therefore, by any changes that are produced in water. Water is the same everywhere, whether produced from the ocean or from the flame of the candle. Where, then, is this water which we get from a candle? I must anticipate a little, and tell you. It evidently comes, as to part of it, from the candle; but is it within the candle beforehand? No. It is not in the candle; and it is not in the air round about the candle which is necessary for its combustion. It is neither in one

nor the other, but it comes from their conjoint action, a part from the candle, a part from the air; and this we have now to trace, so that we may understand thoroughly what is the chemical history of a candle when we have it burning on our table. How shall we get at this? I myself know plenty of ways, but I want *you* to get at it from the association in your own minds of what I have already told you.

II. When Certain Metals act on Water, Hydrogen, a Constituent of a Candle, is Liberated

We had just now the case of a substance which acted upon the water in the way that Sir Humphry Davy showed us, and which I am now going to recall to your minds by making another experiment with it. It is a thing which we have to handle very carefully, for you see, if I allow a little splash of water to come upon this mass, it sets fire to part of it; and if there were free access of air, it would quickly set fire to the whole. Now, this is a metal—a beautiful and bright metal—which rapidly changes in the air, and, as you know, rapidly changes in water. I will put a piece on the water, and you see it burns beautifully, making a floating lamp, using the water in the place of air. Again, if we take a few iron-filings or turnings, and put them in water, we find that they likewise undergo an alteration. They do not

change so much as this potassium does, but they change somewhat in the same way; they become rusty, and show an action upon the water, though in a different degree of intensity to what this beautiful metal does: but they act upon the water in the same manner generally as this potassium. I want you to put these different facts together in your minds. I have another metal here [*zinc*], and when we examined it with regard to the solid substance produced by its combustion, we had an opportunity of seeing that it burned; and I suppose, if I take a little strip of this zinc and put it over the candle, you will see something half-way, as it were, between the combustion of potassium on the water and the action of iron—you see there is a sort of combustion. It has burned, leaving a white ash or residuum, and here also we find that the metal has a certain amount of action upon water.

By degrees we have learned how to modify the action of these different substances, and to make them tell us what we want to know. And now, first of all, I take iron. It is a common thing in all chemical reactions, where we get any result of this kind, to find that it is increased by the action of heat; and if we want to examine minutely and carefully the action of bodies one upon another, we often have to refer to the action of heat. You are aware, I believe, that iron-filings burn beautifully in the air; but I am about to show you an experiment of this kind, because it will impress upon you what

I am going to say about iron in its action on water. If I take a flame and make it hollow;—you know why, because I want to get air to it and into it, and therefore I make it hollow—and then take a few iron-filings and drop them into the flame, you see how well they burn. That combustion results from the chemical action which is going on when we ignite

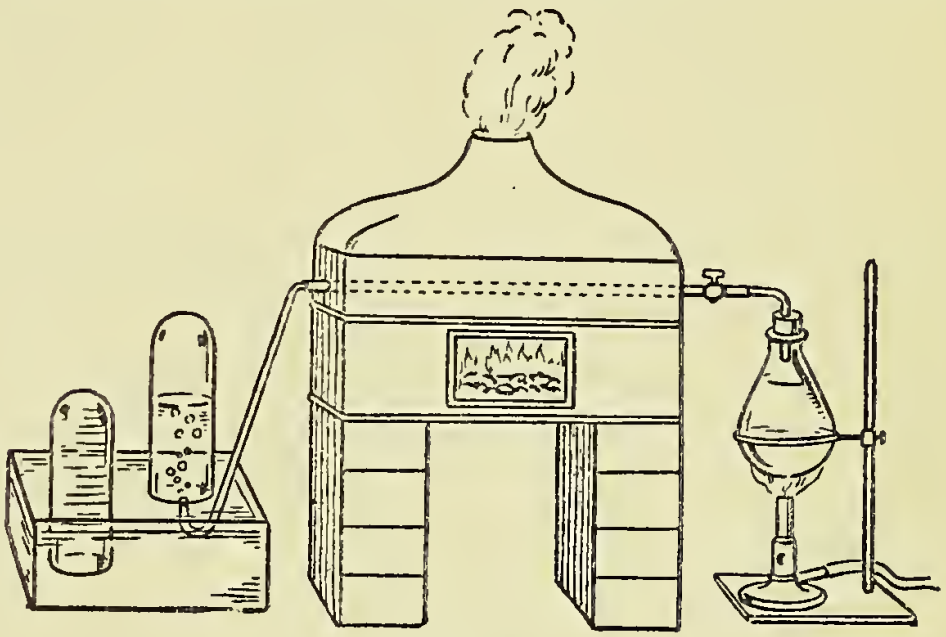


Fig. 14

those particles. And so we proceed to consider these different effects, and ascertain what iron will do when it meets with water. It will tell us the story so beautifully, so gradually and regularly, that I think it will please you very much.

I have here a furnace with a pipe going through it like an iron gun-barrel, and I have stuffed that barrel full of bright iron-turnings, and placed it across the fire, to be made red-hot (Fig. 14). We can

either send air through the barrel to come in contact with the iron, or we can send steam from this little boiler at the end of the barrel. Here is a stopcock which shuts off the steam from the barrel until we wish to admit it. There is some water in these glass jars, which I have coloured blue, so that you may see what happens. Now, you know very well that any steam I might send through that barrel, if it went through into the water, would be condensed; for you have seen that steam cannot retain its gaseous form if it be cooled down: also, if I were to send steam through that barrel, it would be condensed —supposing the barrel were cold: it is, therefore, heated to perform the experiment I am now about to show you. I am going to send the steam through the barrel in small quantities; and you shall judge for yourselves, when you see it issue from the other end, whether it still remains steam. Observe what is taking place in the glass jar. Bubbles of gas are entering it and the water in the jar is being pushed out. What can this gas be? Is it steam? Steam is condensable into water, and when you lower the temperature of steam, you convert it back into fluid water; but I have lowered the temperature of the gas which I have collected in this jar, by passing it through water after it has traversed the iron barrel, and still it does not change back into water. I will take another test and apply to this gas. (I hold the jar in an inverted position, or my substance would escape.) If I now apply a light to

the mouth of the jar, it ignites with a slight noise. That tells you that it is not steam. Steam puts out a fire—it does not burn; but you saw that what I had in that jar burnt. It is hydrogen. We may obtain this substance equally from water produced from the candle-flame as from any other source. When it is obtained by the action of the iron upon the aqueous vapour, it leaves the iron in a state very similar to that in which these filings were after they

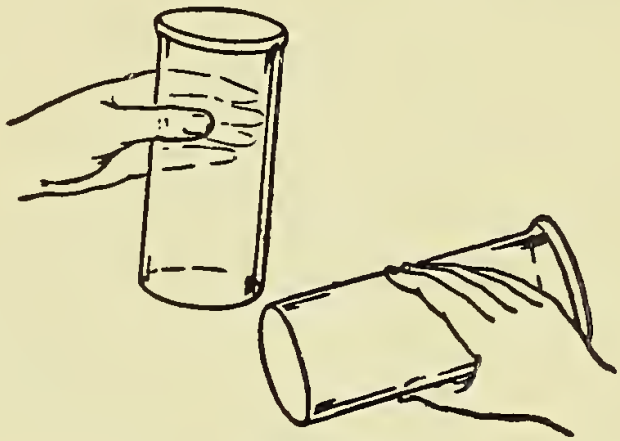


Fig. 15

were burnt. It makes the iron heavier than it was before. So long as the iron remains in the tube and is heated, and is cooled again without the access of air or water, it does not change in its weight; but after having had this current of steam passed over it, it then comes out heavier than it was before, having taken something out of the steam, and having allowed the hydrogen to pass forth. And now, as we have another jar full, I will show you something most interesting. It is a combustible gas; and I might at once take this jar and set fire to the contents,

and show you that it is combustible; but I intend to show you more if I can. It is also a very light substance. Steam will condense: this body will rise in the air, and not condense. Suppose I take another glass jar, empty of all but air: if I examine it with a taper, I shall find that it contains nothing but air. I will now take this jar full of the gas that I am speaking of, and deal with it as though it were a light body. I will hold both upside-down, and turn the one up under the other; and that which did contain the gas procured from the steam, what does it contain now? You will find it now only contains air. But look! Here is the combustible substance (in the top jar) which I have poured out of the one jar into the other. It still preserves its quality, and condition, and independence, and therefore is the more worthy of our consideration as belonging to the products of a candle.

12. Methods of Preparing Hydrogen

Now, this substance which we have just prepared by the action of iron on the steam or water, we can also get by means of those other things which you have already seen act so well upon the water. If I take a piece of potassium, and make the necessary arrangements, it will produce this gas; and if, instead, a piece of zinc, I find, when I come to examine it very carefully, that the main reason why

this zinc cannot act upon the water continuously as the other metal does, is because the result of the action of the water envelops the zinc in a kind of protecting coat. We have learned in consequence, that if we put into our vessel only the zinc and water, they by themselves do not give rise to much action, and we get no result. But suppose I proceed to dissolve off this varnish—this encumbering substance—which I can do by a little acid; the moment I do this, I find the zinc acting upon the water exactly as the iron did, but at the common temperature. The acid in no way is altered, except in its combination with the oxide of zinc, which is produced. I have now poured the acid into the glass, and the effect is as though I were applying heat to cause this boiling up. There is something coming off very abundantly, which is not steam. There is a jar full of it; and you will find that I have exactly the same combustible substance remaining (Fig. 16) in the vessel, when I hold it upside-down, that I produced during the experiment with the iron barrel. This is what we get from water—the same substance which is contained in the candle—hydrogen.

13. More Experiments with Hydrogen

Let us now trace distinctly the connection between these two points. This is hydrogen—a body classed among those things which in Chemistry we call

elements, because we can get nothing else out of them. A candle is not an elementary body, because we can get carbon out of it; we can get this hydrogen out of it, or at least out of the water which it supplies. And this gas has been so named hydrogen, because it is that element which, in association with another, generates water.[1]

Having now been able to get two or three jars of gas, we shall have a few experiments to make, and I want to show you the best way of making these experiments. I am not afraid to show you, for I wish you to make experiments, if you will only make them with care and attention, and the assent of those around you. As we advance in Chemistry, we are obliged to deal with substances which are rather injurious, if in their wrong places—the acids, and heat, and combustible things we use, and they might do harm if carelessly employed. If you want to make hydrogen, you can make it easily from bits of zinc, and sulphuric or hydrochloric acid. Here is what in former times was called the "philosopher's candle." It is a little phial with a cork, and a tube or pipe passing through it. And I am now putting a few little pieces of zinc into it. This little instrument I am going to apply to a useful purpose in our demonstrations—for I want to show you that you can prepare hydrogen, and make some experiments with it as you please at your own homes. Let me here tell you why I am so careful to fill this phial

[1] Ὑδωρ, "water," and γενναω, "I generate."

nearly, and yet not quite full. I do it because the evolved gas, which, as you have seen, is very combustible, is explosive to a considerable extent when mixed with air, and might lead to harm, if you were to apply a light to the end of that pipe before all the air had been swept out of the space above the water. I am now about to pour in the sulphuric

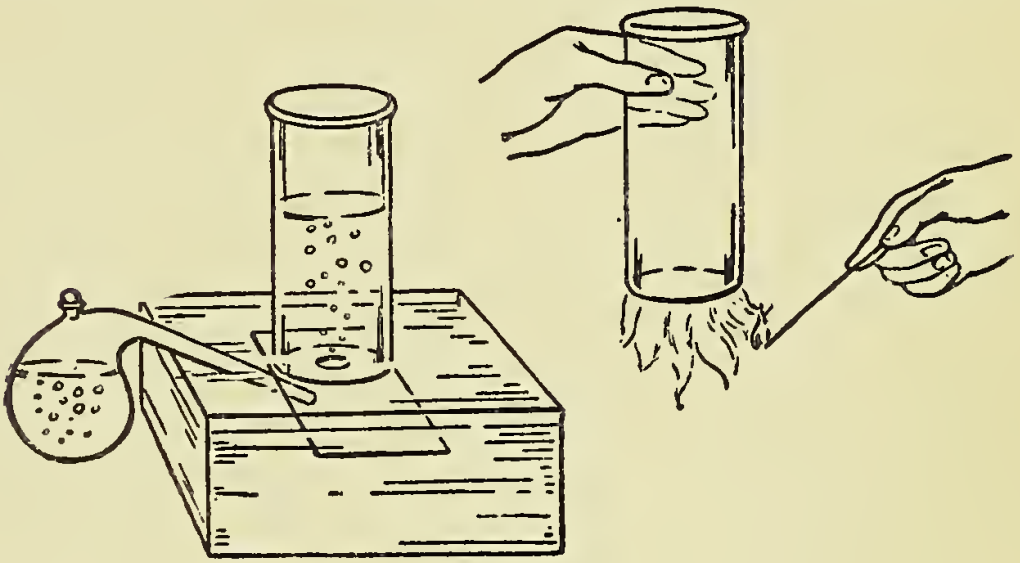


Fig. 16

acid. I have used very little zinc, and more sulphuric acid and water, because I want to keep it at work for some time. I therefore take care in this way to modify the proportions of the ingredients, so that I may have a regular supply—not too quick, and not too slow. Supposing I now take a glass and put it upside down over the end of the tube; because the hydrogen is light I expect that it will remain in that vessel a little while. We will now test the contents of our glass to see if there be hydrogen in

it. When I apply a light there is only a slight " pop " and the gas burns. I don't think there is much air mixed with the gas coming off, so I will now apply a light to the top of the tube. There is the hydrogen burning. There is our philosophical candle. It is a foolish feeble sort of a flame, you may say; but it is so hot that scarcely any common flame gives out so much heat. It goes on burning regularly, and I am now about to put that flame to burn under a certain arrangement, in order that we may examine its results and make use of the information which we may thereby acquire. Inasmuch as the candle produces water, and this gas comes out of the water, let us see what this gives us by the same process of combustion that the candle went through when it burnt in the atmosphere; and for that purpose I am going to put the lamp under this apparatus, in order to condense whatever may arise from the combustion within it. (Fig. 18.) In the course of a short time you will see moisture appearing in the cylinder, and you will get the water running down the side; and the water from this hydrogen flame will have absolutely the same effect upon all our tests, being obtained by the same general process as in the former case.

Fig. 17

This hydrogen is a very beautiful substance. It is so light that it carries things up: it is far lighter than the atmosphere; and I dare say I can show

you this by an experiment which, if you are very clever, some of you may even have skill enough to repeat. Here is our generator of hydrogen, and here are some soapsuds. I have an india-rubber tube connected with the hydrogen generator, and at the end of the tube is a tobacco-pipe. I can thus put the pipe into the suds, and blow bubbles by means of the hydrogen. You observe how the bubbles fall

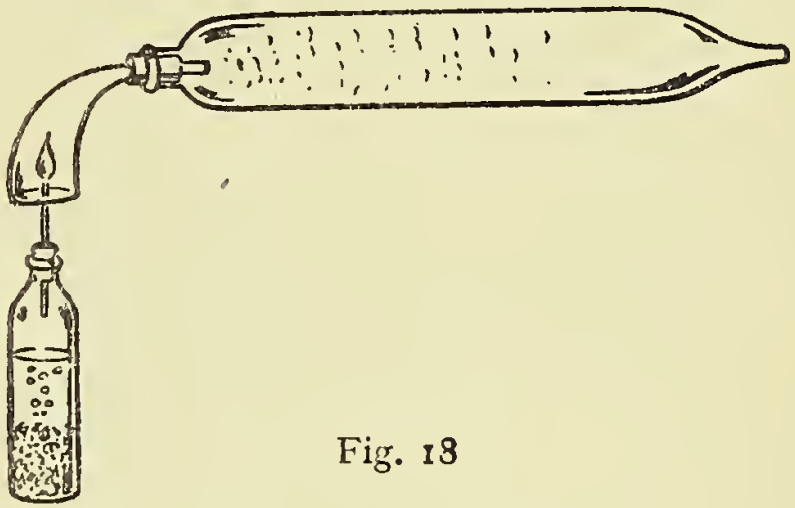


Fig. 18

downwards when I blow them with my warm breath; but notice the difference when I blow them with hydrogen—the bubbles rise to the roof of the theatre. It shows you how light this gas must be in order to carry with it not merely the ordinary soap-bubble, but the larger portion of a drop hanging to the bottom of it. I can show its lightness in a better way than this; larger bubbles than these may be so lifted up; indeed, in former times balloons used to be filled with this gas. I will fasten a balloon on to our generator, and we shall have a stream of

hydrogen here with which we can charge this balloon made of collodion. I need not even be very careful to get all the air out, for I know the power of this gas to carry it up. I think it is inflated sufficiently to be sent up, so I will close it at the mouth and set it free. Ah! it quickly ascends and will remain floating about in the air until the gas escapes. What, do you think, are the comparative weights of water and hydrogen? A pint measure of this hydrogen weighs three-quarters of our smallest weight (a grain), and a cubic foot weighs one-twelfth of an ounce; whereas a pint of water weighs 8,750 grains, and a cubic foot of water weighs almost 1000 ounces. You see, therefore, what a vast difference there is between the weight of a cubic foot of water and a cubic foot of hydrogen.

Hydrogen gives rise to no substance that can become solid, either during combustion or afterwards as a product of its combustion. But when it burns, it produces water only; and if we take a cold glass and put it over the flame, it becomes damp, and you have water produced immediately in appreciable quantity; and nothing is produced by its combustion but the same water which you have seen the flame of the candle produce. It is important to remember that this hydrogen is the only thing in nature which furnishes water as the sole product of combustion.

14. The Decomposition of Water by Electricity

And now we must endeavour to find some additional proof of the general character and composition of water.

We have the power of arranging the zinc which you have seen acting upon the water by the assistance of an acid, in such a manner as to cause all the power to be evolved in the place where we require it. I have behind me a voltaic pile, and I am just about to show you its character and power. I hold here the extremities of the wires which transport this power from behind me, and which I shall cause to act on the water.

We have previously seen what a power of combustion is possessed by the potassium, or the zinc, or the iron-filings; but none of them show such energy as this. I will make *contact between the two terminal wires of the battery; what a brilliant flash of light is produced!* This light is, in fact, produced by a forty-zinc power of burning: it is a power that I can carry about in my hands, through these wires, at pleasure—although, if I applied it wrongly to myself, it would destroy me in an instant, for it is a most intense thing, and the power you see here put forth, if I allow the spark to last while you count five, is equivalent to the power of several thunderstorms, so great is its force.

I am now going to apply this force to water to pull it to pieces, to see what else there is in the water besides hydrogen; because, you remember, when we passed the water through the iron tube, we by no means got the weight of water back which we put in, in the form of steam, though we had a very large quantity of gas evolved. We have now to see what is the other substance present. What effect has an electric current on water? Here are two little platinum-plates which I intend to make the ends of the battery, and this (C) is a little vessel so shaped as to enable me to take it to pieces, and show you its construction. (Fig. 19.) In those two cups I pour mercury, which touches the ends of the wires connected with the platinum-plates. In the vessel (C) I pour some water containing a little acid (but which is put only for the purpose of facilitating the action; it undergoes no change in the process), and connected with the top of the vessel is a bent glass tube (D), which may remind you of the pipe which was connected with the gun barrel in our furnace experiment, and which now passes under the jar (F). I have now adjusted this apparatus, and we will proceed to affect the water in some way or other. In the other case, I sent the water through a tube which was made red-hot; I am now going to pass the electricity through the contents of this vessel. Perhaps I may boil the water; if I do boil the water, I shall get steam; and you know that steam condenses when it gets cold, and you will

therefore see by that whether I do boil the water or not. Perhaps, however, I shall not boil the water, but produce some other effect. You shall have the experiment and see. There is one wire which I will put to this side (A), and here is the other wire which I will put to the other side (B), and you will soon see whether any disturbance takes place. Here it is

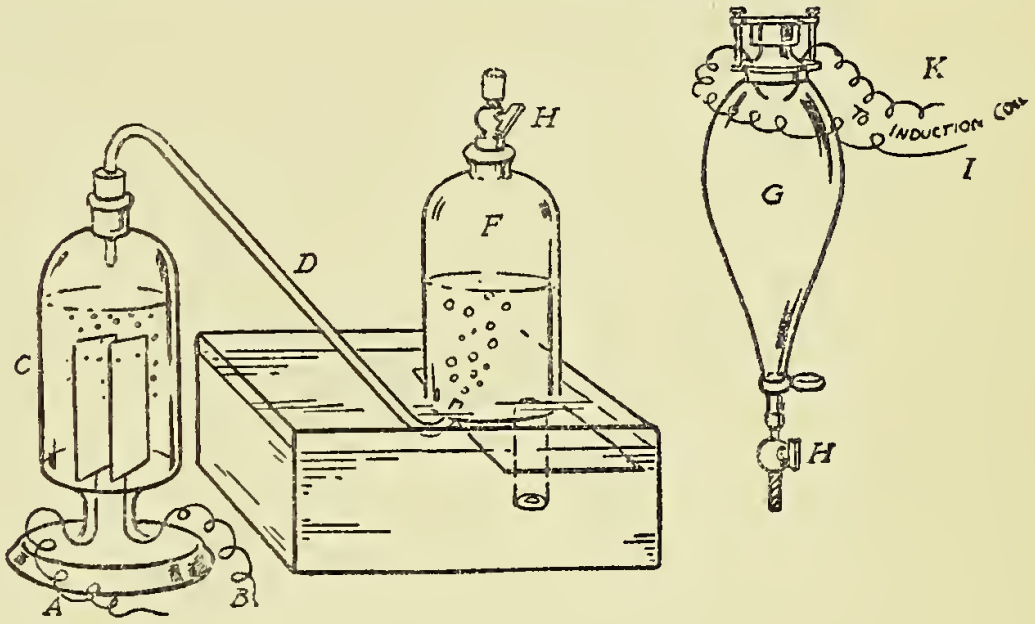


Fig. 19

seeming to boil up famously; but does it boil? Let us see whether that which goes out is steam or not. I think you will soon see the jar (F) will be filled with vapour, if that which rises from the water is steam. But can it be steam? Why, certainly not; because there it remains, you see, unchanged. There it is standing over the water, and it cannot therefore be steam, but must be a permanent gas of some sort. What is it? Is it hydrogen? Is it anything else?

Well, we will examine it. If it is hydrogen, it will burn. I will now apply a light to it. You see it is certainly combustible, but not combustible in the way that hydrogen is. Hydrogen would not have given you that noise; but the colour of that light, when the thing did burn, was like that of hydrogen: it will, however, burn without contact with the air. That is why I have chosen this other form of apparatus, for the purpose of pointing out to you what are the particular circumstances of this experiment. In place of an open vessel I have taken one that is closed; and I am going to show you that that gas, whatever it may be, can burn without air, and in that respect differs from a candle, which cannot burn without the air. And our manner of doing this is as follows:—I have here a glass vessel (G) which is fitted with two platinum-wires (I K), through which I can apply electricity; and we can put the vessel on the air-pump and exhaust the air, and when we have taken the air out we can fasten it on to this jar (F), and let into the vessel that gas which was formed by the action of the voltaic battery upon the water, and which we have produced by changing the water into it—for I may go as far as this, and say we have really, by that experiment, changed the water into that gas. We have not only altered its condition, but we have changed it really and truly into that gaseous substance, and all the water is there which was decomposed by the experiment. As I screw this vessel (G H) on here (H),

and make the tubes well connected, and when I open the stopcocks (H H), if you watch the level of the water (in F), you will see that the gas will rise. I will now close the stopcocks, as I have drawn up as much as the vessel can hold, and I will pass an electric spark, from an induction coil, through the gas. The vessel was quite clear and bright at first, but it has now become dim with a deposit of water. I will again connect it to our gas reservoir, for that is what the jar (F) really is: and, as I open the stopcocks you see that the water rises; this indicates that (G) must be filling. "But why is the jar empty after each explosion?" you may ask. Because the vapour or gas into which that water has been resolved by the battery explodes under the influence of the spark, and changes into water; and by-and-by you will see in this upper vessel some drops of water trickling down the sides and collecting at the bottom.

We are here dealing with water entirely, without reference to the atmosphere. The water of the candle had the atmosphere helping to produce it; but in this way it can be produced independently of the air. Water, therefore, ought to contain that other substance which the candle takes from the air, and which, combining with the hydrogen, produces water.

I will now dip the poles—the metallic ends of this battery—into water (Fig. 20), and see what will happen when they are kept far apart. I place one

here (at A), and the other there (at B), and I have little shelves with holes which I can put upon each pole, and so arrange them that whatever escapes from the two ends of the battery will appear as separate gases; for you saw that the water did not become vaporous, but gaseous. The wires are now in perfect and proper connection with the vessel containing the water; and you see the bubbles

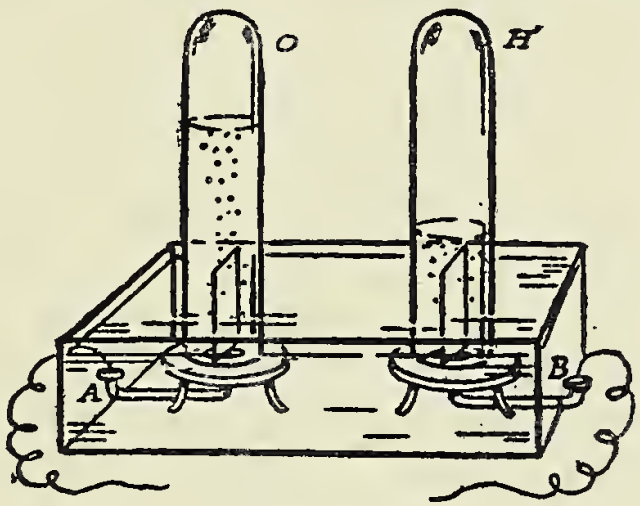


Fig. 20

rising: let us collect these bubbles and see what they are. Here is a glass cylinder (O); I fill it with water and put it over one end (A) of the pile; and I will take another (H) and put it over the other end (B) of the pile. And so now we have a double apparatus, with both places delivering gas. Both these jars will fill with gas. There they go, that to the right (H) filling very rapidly; the one to the left (O) filling not so rapidly. I should have twice as much in this H) as I have in that (O). Both these gases

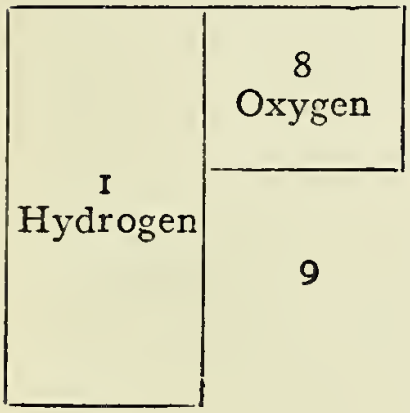
are colourless; they stand over the water without condensing; they are alike in all things—I mean in all *apparent* things; and we have here an opportunity of examining these bodies and ascertaining what they are. Their bulk is large, and we can easily apply experiments to them. I will take this jar (H) first, and will ask you to be prepared to recognise hydrogen.

Think of all its qualities—the light gas which stood well in inverted vessels, burning with a pale flame at the mouth of the jar—and see whether this gas does not satisfy all these conditions. If it be hydrogen, it will remain here while I hold this jar inverted. It burns when a light is applied to the mouth of the jar; it is evidently hydrogen.

What is there now in the other jar? You know that the two together made an explosive mixture. But what can this be which we find as the other constituent in water, and which must therefore be that substance which made the hydrogen burn? We know that the water we put into the vessel consisted of the two things together. We find one of these in hydrogen: what must that other be which was in the water before the experiment, and which we now have by itself? I am about to put this lighted splinter of wood into the gas. The gas itself will not burn, but it will rekindle the glowing splinter. See how it invigorates the combustion of the wood, and how it makes it burn far better than the air would make it burn; and now you see by

itself that very other substance which is contained in the water, and which, when the water was formed by the burning of the candle, must have been taken from the atmosphere. What shall we call it, A, B, or C? Let us call it O—call it "Oxygen": it is a very good distinct-sounding name. This, then, is the oxygen which was present in the water, forming so large a part of it.

We shall now begin to understand more clearly our experiments and researches; because, when we have examined these things once or twice, we shall soon see why a candle burns in the air. When we have in this way analysed the water—that is to say, separated, or electrolysed its parts out of it—we get two volumes of hydrogen, and one of the body that burns it. And these two are represented to us on the following diagram, with their weights also stated; and we shall find that the oxygen is a very heavy body by comparison with the hydrogen. It is the other element in water.



Oxygen . . .	88·9
Hydrogen . . .	11·1
Water . . .	100·0

15. Oxygen

I had better, perhaps, tell you now how we get this oxygen abundantly, having shown you how we can separate it from water. Oxygen, as you will immediately imagine, exists in the atmosphere; for how should the candle burn to produce water without it? Such a thing would be absolutely impossible, and chemically impossible, without oxy-

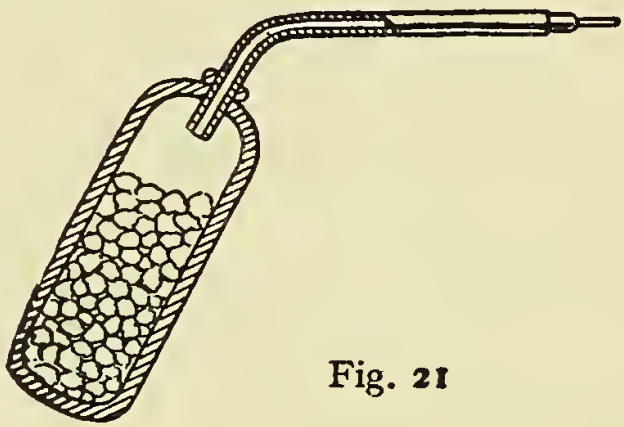


Fig. 21

gen. Can we get it from the air? Well, there are some very complicated and difficult processes by which we can get it from the air; but we have better processes.

There is a substance called the black oxide of manganese: it is a very black-looking mineral, but very useful, and when made red-hot it gives out oxygen. Here is an iron bottle which has had some of this substance put into it, and there is a tube fixed to it, and a fire ready made, and I will put that

retort into the fire, for it is made of iron, and can stand the heat.

Here is a salt called chlorate of potassium, which is now made in large quantities for bleaching, and chemical and medical uses, and for pyrotechnic

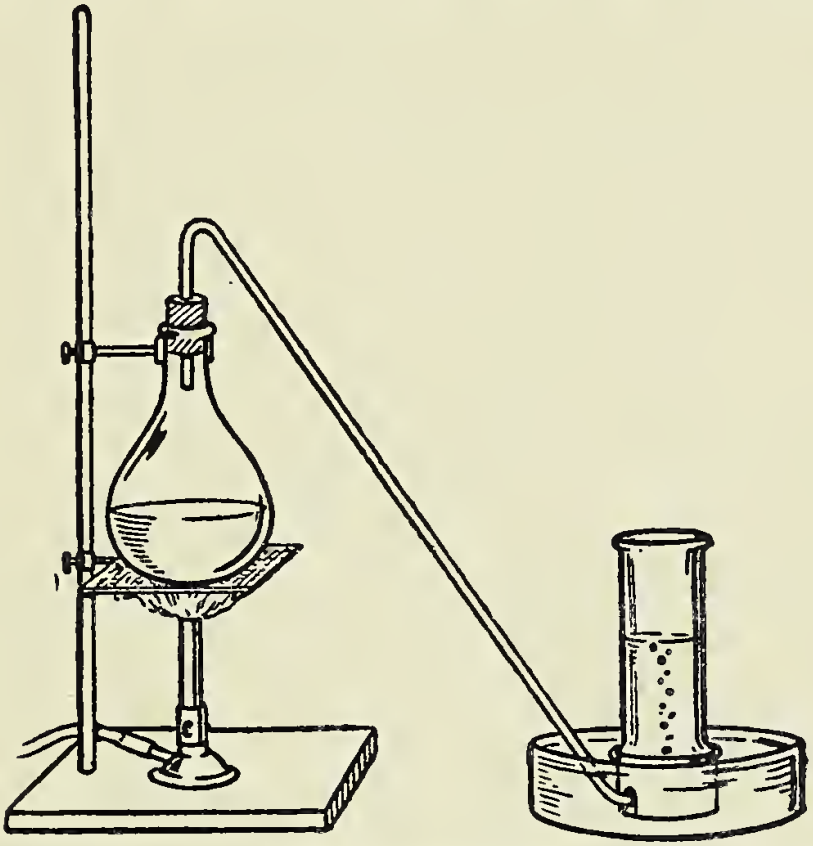


Fig. 21A. Apparatus usually used for preparing Oxygen

and other purposes. I will take some and mix it with some of the oxide of manganese (oxide of copper, or oxide of iron would do as well); and if I put these together in a retort, far less than a red heat is sufficient to evolve this oxygen from the mixture. I am not preparing to make much, because we only want sufficient for our experiments; only,

as you will see immediately, if I use too small a charge, the first portion of the gas will be mixed with the air already in the retort, and I should be obliged to sacrifice the first portion of the gas, because it would be so much diluted with air; the first portion must therefore be thrown away. You will find in this case that a common spirit-lamp is quite sufficient for me to get the oxygen. I will conduct the gas liberated through a bent tube and collect it in the same way as I collected hydrogen, by upward displacement of water. See how freely the gas is coming over from that small portion of the mixture. We will examine it, and see what are its properties. Now, in this way we are producing, as you will observe, a gas just like the one we had in the experiment with the battery, transparent, undissolved by water, and presenting the ordinary visible properties of the atmosphere. (As this first jar contains the air, together with the first portions of the oxygen set free during the preparation, we will carry it out of the way, and be prepared to make our experiments in a regular, dignified manner.) And, inasmuch as that power of making wood, wax, or other things burn, was so marked in the oxygen we obtained by means of the voltaic battery from water, we may expect to find the same property here. We will try it. I will lower a lighted taper (Fig. 22) into a jar of oxygen. See how brightly and how beautifully it

Fig. 22

burns! You can also see more than this,—you will perceive it is a heavy gas, whilst the hydrogen would go up like a balloon, or even faster than a balloon, when not encumbered with the weight of the envelope. You may easily see that although we obtained from water twice as much in volume of the hydrogen as of oxygen, it does not follow that we have twice as much in weight—because one is heavy, and the other a very light gas. We have means of weighing gases or air; but without stopping to explain that, let me just tell you what their respective weights are. The weight of a pint of hydrogen is three-quarters of a grain; the weight of the same quantity of oxygen is nearly twelve grains. This is a very great difference. The weight of a cubic foot of hydrogen is one-twelfth of an ounce; and the weight of a cubic foot of oxygen is one ounce and a third. And so we might go on and come to masses of matter which may be weighed in the balance, and which we can take account of as to hundredweights and as to tons, as you will see almost immediately.

Now, as regards this very property of oxygen supporting combustion, which we may compare to air, I will take a piece of candle to show it you in a rough way, and the result will be rough. There is our candle burning in the air: how will it burn in oxygen? I have here a jar of this gas, and I am about to put it over the candle for you to compare the action of this gas with that of the air. Why, look at

it: it looks something like the light you saw at the poles of the voltaic battery. Think how vigorous that action must be! And yet, during all that action, nothing more is produced than what is produced by the burning of the candle in air. We have the same production of water, and the same phenomena exactly, when we use this gas instead of air, as we have when the candle is burnt in air.

But now we have got a knowledge of this new substance, we can look at it a little more distinctly, in order to satisfy ourselves that we have got a good general understanding of this part of the product of a candle. It is wonderful how great the supporting powers of this substance are as regards combustion. For instance, here is a lamp which, simple though it be, is the original, I may say, of a great variety of lamps which are constructed for divers purposes —for light-houses, microscopic illuminations, and other uses; and if it were proposed to make it burn very brightly, you would say, "If a candle burnt better in oxygen, will not a lamp do the same?" Why, it will do so.

Here I have a tube coming from our oxygen reservoir, and I am about to apply it to this flame, which I will previously make burn badly on purpose. There comes the oxygen: what a combustion that makes! But if I shut it off, what becomes of the lamp? It relapses to its former dimness.

It is wonderful how, by means of oxygen, we get combustion accelerated. But it does not affect

merely the combustion of hydrogen, or carbon, or the candle; it exalts all combustions of the common kind. We will take one which relates to iron, for instance, as you have already seen iron burn a little in the atmosphere. Here is a jar of oxygen, and this is a piece of iron wire; but if it were a bar as thick as my wrist, it would burn the same. I first attach a little piece of wood to the iron, I then set the wood on fire, and let them both down

Fig. 23

Fig. 24

together into the jar. The wood is now alight, and there it burns as wood should burn in oxygen; but it will soon communicate its combustion to the iron. The iron is now burning brilliantly, and will continue so for a long time. As long as we supply oxygen, so long can we carry on the combustion of the iron, until the latter is consumed. (Fig. 23.)

We will now put that on one side, and take some other substance; but we must limit our experiments, for we have not time to spare for all the illustrations you would have a right to see if we had more time.

We will take a piece of sulphur—you know how sulphur burns in the air—well, we put it into the oxygen, and you will see that whatever can burn in air, can burn with a far greater intensity in oxygen, leading you to think that perhaps the atmosphere itself owes all its power of combustion to this gas. The sulphur is now burning very quietly in the oxygen; but you cannot for a moment mistake the very high and increased action which takes place when it is so burnt, instead of being burnt merely in common air. (Fig. 24.)

I am now about to show you the combustion of another substance—phosphorus. I can do it better for you here than you can do it at home. This is a very combustible substance; and if it be so combustible in air, what might you expect it would be in oxygen? I am about to show it to you not in its fullest intensity, for if I did so we should almost blow the apparatus up—I may even now crack the jar, though I do not want to break things carelessly. You see how it burns in the air. But what a glorious light it gives out when I introduce it into oxygen! There you see the solid particles going off which cause that combustion to be so brilliantly luminous.

16. Synthesis of Water from Hydrogen and Oxygen

Thus far we have tested this power of oxygen, and the high combustion it produces by means of other substances. We must now, for a little while longer, look at it as regards the hydrogen. You know, when we allowed the oxygen and the hydrogen derived from the water to mix and burn together, we had a little explosion. You remember, also, that when I burnt the oxygen and the hydrogen in a jet together, we got very little light, but great heat. I am now about to set fire to oxygen and hydrogen, mixed in the proportion in which they occur in water. Here is a vessel containing one volume of oxygen and two volumes of hydrogen. This mixture is exactly of the same nature as the gas we just now obtained from the voltaic battery: it would be far too much to burn at once; I have therefore arranged to blow soap-bubbles with it, and burn those bubbles, that we may see by a general experiment or two how this oxygen supports the combustion of the hydrogen. First of all, we will see whether we can blow a bubble. Here I have a bubble. I will explode it on the palm of my hand. I am afraid to fire a bubble from the end of the pipe, because the explosion would pass up into the jar and blow it to pieces. This oxygen then will unite with the hydrogen, as you see by the phenomena, and hear by the sound, with the utmost

readiness of action, and all its powers are then taken up in its neutralisation of the qualities of the hydrogen.

So now I think you will perceive the whole history of water with reference to oxygen and the air, from what we have said before. Why does a piece of potassium decompose water? Because it finds oxygen in the water. What is set free when I put it in the water?

Hydrogen is set free, and the hydrogen burns; but the potassium itself combines with oxygen; and this piece of potassium, in taking the water apart—the water, you may say, derived from the combustion of the candle—takes away the oxygen which the candle took from the air, and so sets the hydrogen free; and even if I take a piece of ice, and put a piece of potassium upon it, the beautiful affinities by which the oxygen and the hydrogen are related are such, that the ice will absolutely set fire to the potassium. I show this to you to-day, in order to enlarge your ideas of these things, and that you may see how greatly results are modified by circumstances. There is the potassium on the ice, producing a sort of volcanic action.

It will be my place, having pointed out these anomalous actions, to show you that none of these extra and strange effects are met with by us—that none of these strange and injurious actions takes place when we are burning, not merely a candle, but gas in our streets, or fuel in our fireplaces, so

long as we confine ourselves within the laws that Nature has made for our guidance.

Bibliothèque des ELEVES COLLÈGE ST-JEAN 8406 - 91e Rue Edmonton, Alta.

17. Composition of the Atmosphere

We have now seen that we can produce hydrogen and oxygen from the water that we obtained from the candle. Hydrogen, you know, comes from the candle, and oxygen, you believe, comes from the air. But then you have a right to ask me, "How is it that the air and the oxygen do not equally well burn the candle?" If you remember what happened when I put a jar of oxygen over a piece of candle, you recollect there was a very different kind of combustion to that which took place in the air. Now, why is this? It is a very important question, and one I shall endeavour to make you understand: it relates most intimately to the nature of the atmosphere, and is most important to us.

We have several tests for oxygen besides the mere burning of bodies. You have seen a candle burnt in oxygen, or in the air; you have seen phosphorus burnt in the air, or in oxygen; and you have seen iron-filings burnt in oxygen. But we have other tests besides these, and I am about to refer to one or two of them for the purpose of carrying your conviction and your experience further. Here we have a vessel of oxygen. I will show its presence to you: if I take a glowing splinter and put it into

that oxygen, you know, by the experience you gained the last time we met, what will happen; if I put that spark into the jar, it will tell you whether we have oxygen here or not. Yes! We have proved it by combustion; and now here is another test for oxygen, which is a very curious and useful one. I have here two jars full of gas, with a plate between them to prevent their mixing. One jar is full of oxygen and the other of nitric oxide. I take the plate away, and the gases are creeping one into the other. "What happens?" say you: "they together produce no such combustion as was seen in the case of the candle." But see how the presence of oxygen is told by its association with this other substance. What a beautifully coloured gas I have obtained in this way, showing me the presence of the oxygen! In the same way we can try this experiment by mixing common air with this test gas. Here is a jar containing air—such air as the candle would burn in—and here is a jar or bottle containing the test gas. I let them come together, and you see the result: the contents of the test bottle are flowing into the jar of air, and you see I obtain exactly the same kind of action as before, and that shows me that there is oxygen in the air—the very same substance that has been already obtained by us from the water produced by the candle. But then, beyond that, how is it that the candle does not burn in air as well as in oxygen? We will come to that point at once. I have here two jars; they are filled to the

same height with gas, and the appearance to the eye is alike in both, and I really do not know at present which of these jars contains oxygen and which contains air, although I know they have previously been filled with these gases. But here is our test gas; it is being produced in this flask and carried along a delivery tube to the point where it is required. I will arrange our two jars, containing oxygen and air respectively, so that they have their mouths under water. I will dip the tube, delivering the test gas, under each jar in turn. A very curious thing happens. The redness appears but disappears in a few seconds, having dissolved in the water. I may go on in this way, putting in more and more of the test gas, until I come to something left behind which will not redden any longer by the use of that particular body that rendered the air and the oxygen red. Why is that? It is because there is, besides oxygen, something else present which is left behind. Let us call this gas X until we find out its real name.

Now, you will begin to understand what I am about to say. You saw that when I burnt phosphorus in a jar, as the smoke produced by the phosphorus and the oxygen of the air condensed, it left a good deal of gas unburnt, just as this red gas left something untouched—there was, in fact, this gas left behind, which the phosphorus cannot touch, which the reddening gas cannot touch, and this something is not oxygen, and yet is part of the atmosphere.

So that is one way of opening out air into the two things of which it is composed—oxygen, which burns our candles, our phosphorus, or anything else; and this other substance—nitrogen—which will not burn them. This other part of the air is by far the larger proportion, and it is a very curious body, when we come to examine it; it is remarkably curious, and yet you say, perhaps, that it is very uninteresting. It is uninteresting in some respects because of this—that it shows no brilliant effects of combustion. If I test it with a taper as I do oxygen and hydrogen, it does not burn like hydrogen, nor does it make the taper burn like oxygen. Try it in any way I will, it does neither the one thing nor the other: it will not take fire; it will not let the taper burn; it puts out the combustion of everything. There is nothing that will burn in it in common circumstances. It has no smell; it is not sour; it does not dissolve in water; it is neither an acid nor an alkali; it is as indifferent to all our organs as it is possible for a thing to be. And you might say, "It is nothing; it is not worth chemical attention; what does it do in the air?" Ah! then come our beautiful and fine results shown us by an observant philosophy. Suppose, in place of having nitrogen, or nitrogen and oxygen, we had pure oxygen as our atmosphere; what would become of us? You know very well that a piece of iron lit in a jar of oxygen goes on burning to the end. When you see a fire in an iron grate, imagine where the

grate would go to if the whole of the atmosphere were oxygen. The grate would burn up more powerfully than the coals—for the iron of the grate itself is even more combustible than the coals which we burn in it. A fire put into the middle of a locomotive would be a fire in a magazine of fuel, if the atmosphere were oxygen. The nitrogen lowers it down and makes it moderate and useful for us, and then, with all that, it takes away with it the fumes that you have seen produced from the candle, disperses them throughout the whole of the atmosphere, and carries them away to places where they are wanted to perform a great and glorious purpose of good to man, for the sustenance of vegetation; and thus does a most wonderful work, although you say, on examining it, "Why, it is a perfectly indifferent thing." This nitrogen in its ordinary state is an inactive element; no action short of the most intense electric force, and then in the most infinitely small degree, can cause the nitrogen to combine directly with the other element of the atmosphere, or with other things round about it; it is a perfectly indifferent, and therefore, so to say, a safe substance.

But before I take you to that result, I must tell you about the atmosphere itself. I have given below the composition of one hundred parts of atmospheric air:

	Bulk	Weight
Oxygen	20	22·3
Nitrogen	80	77·7
	100	100·0

It is a true analysis of the atmosphere, so far as regards the quantity of oxygen and the quantity of nitrogen present. By our analysis, we find that 5 pints of the atmosphere contain only 1 pint of oxygen, and 4 pints, or 4 parts, of nitrogen by bulk. That is our analysis of the atmosphere. It requires all that quantity of nitrogen to reduce the oxygen down, so as to be able to supply the candle properly with fuel, so as to supply us with an atmosphere which our lungs can healthily and safely breathe; for it is just as important to make the oxygen right for us to breathe, as it is to make the atmosphere right for the burning of the fire and the candle.

18. The Pressure of the Atmosphere

But now for this atmosphere. First of all, let me tell you the weight of these gases. A pint of nitrogen weighs $10\frac{7}{10}$ grains, or a cubic foot weighs $1\frac{1}{6}$ ounce. That is the weight of the nitrogen. The oxygen is heavier: a pint of it weighs $11\frac{9}{10}$ grains, and a cubic foot weighs $1\frac{3}{4}$ ounce. A pint of air weighs about $10\frac{7}{10}$ grains, and a cubic foot $1\frac{1}{5}$ ounce.

You have asked me several times, and I am very glad you have, "How do you weigh gases?" I will show you; it is very simple, and easily done. Here is a balance, and here a copper bottle, made as light as we can consistent with due strength, turned very

nicely in the lathe, and made perfectly air-tight, with a stopcock, which we can open and shut, which at present is open, and therefore allows the bottle to be full of air. I have here a nicely adjusted balance, in which I think the bottle in its present condition

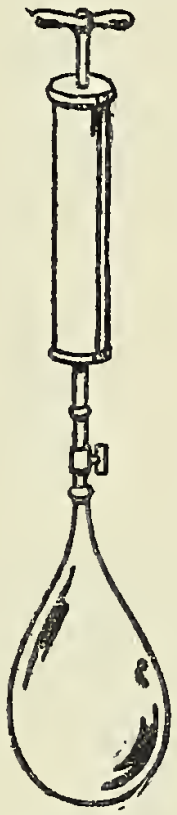


Fig. 25

will be balanced by the weight on the other side. And here is a pump by which we can force the air into this bottle, and with it we will force in twenty volumes of air, as measured by the pump. (Fig. 25.) We will shut that in and put it in the balance. See how it sinks: it is much heavier than it was. By what? By the air that we have forced into it by the pump. There is not a greater *bulk* of air, but there is the

same bulk of *heavier* air, because we have forced in air upon it. And that you may have a fair notion in your mind as to how much this air measures, here is a jar full of water. (Fig. 26.) We will open that copper vessel into this jar, and let the air return to

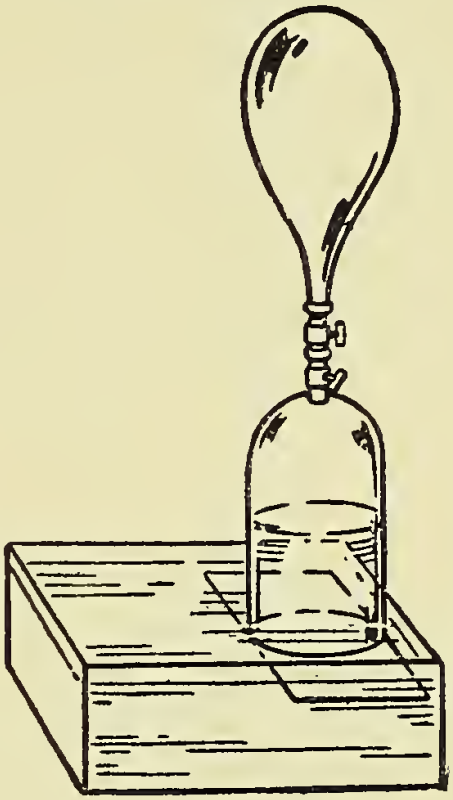


Fig. 26

its former state. All I have to do now is to screw them tightly together, and to turn the taps, when there, you see, is the bulk of the twenty pumps of air which I forced into the bottle; and to make sure that we have been quite correct in what we have been doing, we will take the bottle again to the balance, and, if it is now counterpoised by the

original weight, we shall be quite sure we have made our experiment correctly. It is balanced; so, you see, we can find out the weight of the extra volumes of air forced in, in that way, and by that means we are able to ascertain that a cubic foot of air weighs $1\frac{1}{5}$ ounce. But that small experiment will by no means convey to your mind the whole literal truth of this matter. It is wonderful how it accumulates when you come to larger volumes.

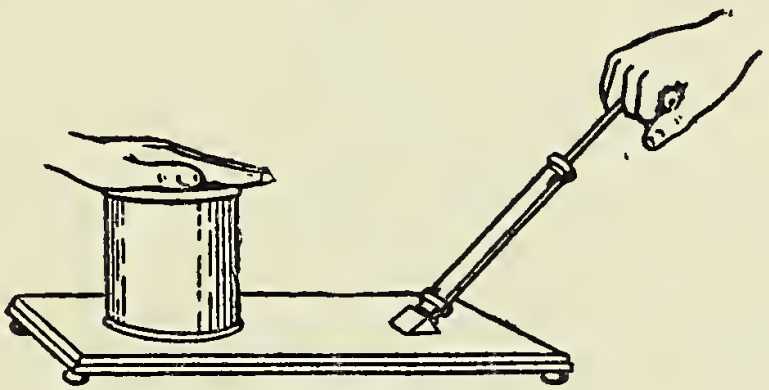


Fig. 27

What do you think the air in a box 3 feet long, 2 feet broad, and 2 feet deep, will weigh? Almost one pound; and I have calculated that the air in this room, which is 50 feet long, 30 feet wide, and 25 feet high, weighs about a ton.

Having given you that little illustration with respect to the weight of the air, let me show you certain consequences of it. You have a right to them, because you would not understand so much without it. Suppose I take a pump somewhat similar to the one I had a little while ago to force

air into the bottle, and suppose I place it in such a manner that by certain arrangements I can apply my hand to it. My hand moves about in the air so easily that it seems to feel nothing, and I can hardly get velocity enough by any motion of my own in the atmosphere to make sure that there is much resistance to it. But when I put my hand on the air-pump receiver (Fig. 27) and pump out the air you see what happens. Why is my hand fastened to this place, and why is it that I can hardly get my hand away? Why is this? It is the weight of the air—the weight of the air that is above.

I have another experiment here, which I think will explain to you more about it. When the air is pumped from underneath the bladder which is stretched over this glass, you will see the effect in another shape: the top is quite flat at present, but I will make a very little motion with the pump, and now look at it—see how it has gone down, see how it is bent in. You will see the bladder go in more and more, until at last I expect it will be driven in and broken by the force of the atmosphere pressing upon it. Ah! it has broken under the weight of the air pressing on it, and you can easily understand how that is. The particles that are piled up in the atmosphere stand upon each other, as these five cubes do. (Fig. 28.) You can easily conceive that four of these five cubes are resting upon the bottom one, and if I take that away, the others will all sink down. So it is with the atmosphere: the air that is

above is sustained by the air that is beneath; and when the air is pumped away from beneath them, the change occurs which you saw when I placed my hand on the air-pump, and which you saw in the case of the bladder, and which you shall see better here. I have tied over this jar a piece of sheet india-rubber, and I am now about to take away the air

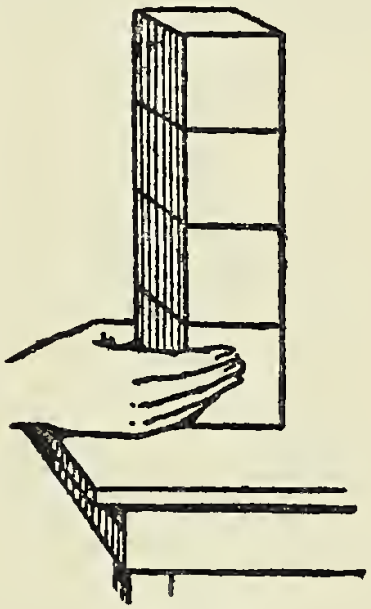


Fig. 28

from the inside of the jar; and if you will watch the india-rubber—which acts as a partition between the air below and the air above—you will see, when I pump, how the pressure shows itself. See where it is going to—I can actually put my hand into the jar; and yet this result is only caused by the great and powerful action of the air above. How beautifully it shows this curious circumstance!

Here (Fig. 28A) is a little apparatus consisting of

two hollow brass hemispheres, closely fitted together and having connected with it a pipe and a cock, through which we can exhaust the air from the inside. The two halves are easily taken apart, while the air is left within, yet you will see, when we exhaust it by-and-by, no power of any two of you will be able to pull them apart. Every square inch of surface that is contained in the area of that vessel

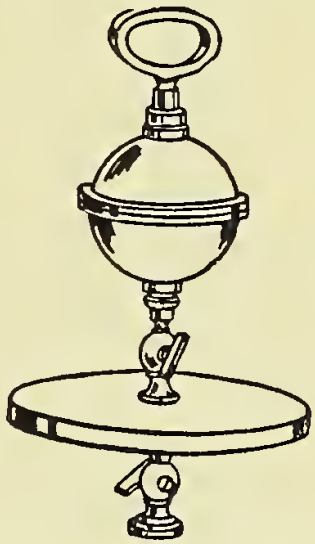


Fig. 28A. Magdeburg Hemispheres

sustains fifteen pounds by weight, or nearly so, when the air is taken out; and you may try your strength presently in seeing whether you can overcome that pressure of the atmosphere.

Here is another very pretty thing—the boys' sucker, only refined by the philosopher. We young ones have a perfect right to take toys, and make them into philosophy, inasmuch as nowadays we are turning philosophy into toys. Here is a sucker, only

it is made of india-rubber. If I clap it upon the table, you see at once it holds. Why does it hold? I can slip it about, and yet if I try to pull it up, it seems as if it would pull the table with it. I can easily make it slip about from place to place; but only when I bring it to the edge of the table can I get it off. It is only kept down by the pressure of the atmosphere above. We have a couple of them;

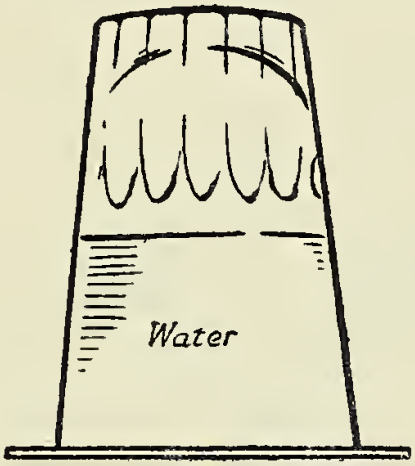


Fig. 28B

and if you take these two and press them together, you will see how firmly they stick. And, indeed, we may use them as they are proposed to be used, to stick against windows, or against walls, where they will adhere for an evening, and serve to hang anything on that you want. I think, however, that you boys ought to be shown experiments that you can make at home; and so here is a very pretty experiment in illustration of the pressure of the atmosphere. Here is a tumbler of water. Suppose I were to ask you to turn that tumbler upside-down,

so that the water shall not fall out, and yet not be kept in by your hand, but merely by using the pressure of the atmosphere. Could you do that? Take a wine-glass, either quite full or half full of water, and put a flat card on the top, turn it upside down, and then see what becomes of the card and of the water. The air cannot get in because the water by its capillary attraction round the edge keeps it out.

I think this will give you a correct notion of what you may call the materiality of the air; and when

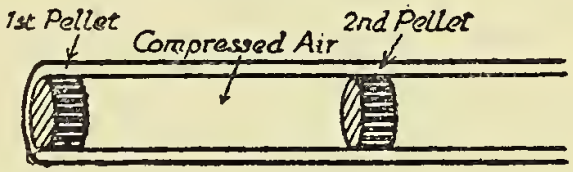


Fig. 28c. The principle of the popgun

I tell you that this room holds more than a ton, you will begin to think that air is something very serious. I will make another experiment, to convince you of this positive resistance. There is that beautiful experiment of the popgun, made so well and so easily, you know, out of a quill, or a tube, or anything of that kind. We take a slice of potato, for instance, or an apple, and take the tube and cut out a pellet, as I have now done, and push it to one end. I have made that end tight; and now I take another piece and put it in: it will confine the air that is within the tube perfectly and completely for our purpose. I shall now find it absolutely impossible by any

force of mine to drive that little pellet close up to the other. It cannot be done. I may press the air to a certain extent, but if I go on pressing, long before it comes to the second, the confined air will drive the front one out with a force something like that of gunpowder; for gunpowder is in part dependent upon the same action that you see here exemplified.

Fig. 28D

I saw the other day an experiment which pleased me much, as I thought it would serve our purpose here. (I ought to have held my tongue for four or five minutes before beginning this experiment, because it depends upon my lungs for success.) By the proper application of air I expect to be able to drive this egg out of one cup into the other by the force of my breath; but if I fail, it is in a good cause. The air which I blow goes downwards between the egg and the cup, and makes a blast under the egg,

and is thus able to lift a heavy thing—for a full egg is a very heavy thing for air to lift. If you want to make the experiment, you had better boil the egg quite hard first, and then you may very safely try to blow it from one cup to the other, with a little care.

I have now kept you long enough upon this property of the weight of the air, but there is another thing I should like to mention. You saw the way in which, in this popgun, I was able to drive the second piece of potato half or two-thirds of an inch before the first piece started, by virtue of the elasticity of the air—just as I pressed into the copper bottle the particles of air by means of the pump. Now, this depends upon a wonderful property in the air, namely, its elasticity; and I should like to give you a good illustration of this. If I take anything that confines the air properly, as this membrane, which also is able to contract and expand so as to give us a measure of the elasticity of the air, and confine in this bladder a certain portion of air; and then, if we take the atmosphere off from the outside of it, just as in these cases we put the pressure on—if we take the pressure off, you will see how it will then go on expanding and expanding, larger and larger, showing you that wonderful property of the air, its elasticity, its compressibility, and expansibility, to an exceedingly large extent, and which is very essential for the purposes and services it performs in the economy of creation.

We will now turn to another very important part of our subject, remembering that we have examined the candle in its burning, and have found that it gives rise to various products. We have the products, you know, of soot, of water, and of something else which you have not yet examined. We have collected the water, but have allowed the other things to go into the air. Let us now examine some of these other products.

19. Carbon Dioxide—Another Product of the Combustion of a Candle

Here is an experiment which I think will help you in part in this way. We will put our candle there, and place a chimney over it. (Fig. 29.) I think my candle will go on burning, because the air passage is open at the bottom and the top. In the first place, you see the moisture appearing—that you know about. It is water produced from the candle by the action of the air upon its hydrogen. But, besides that, something is going out at the top: it is not moisture—it is not water—it is not condensable; and yet, after all, it has very singular properties. You will find that the air coming out of the top of our chimney is nearly sufficient to blow out the light I am holding to it; and if I put the light fairly opposed to the current, it will blow it quite out. You

will say that is as it should be; and I am supposing that you think it ought to do so, because the nitrogen does not support combustion, and ought to put the candle out, since the candle will not burn in nitrogen. But is there nothing else there than nitrogen? I must now anticipate—that is to say, I must use my

Fig. 29

own knowledge to supply you with the means that we adopt for the purpose of ascertaining these things, and examining such gases as these. I will take an empty bottle—here is one—and if I hold it over this chimney, I shall get the combustion of the candle below sending its results into the bottle above; and we shall soon find that this bottle contains, not merely an air that is bad as regards the combustion of a taper put into it, but having other properties.

Let me take a little quicklime and pour some common water on to it—the commonest water will do. I will stir it a moment, then pour it through a piece of filtering paper in a funnel, and we shall very quickly have a clear water proceeding to the bottle below, as I have here. I have plenty of this water in another bottle; but, nevertheless, I should like to use the lime-water that was prepared before you, so that you may see what its uses are. If I take some of this beautiful clear lime-water, and pour it into this jar, which has collected the air from the candle, you will see a change coming about. Do you see that the water has become quite milky? Observe, that will not happen with air merely. Here is a bottle filled with air; and if I put a little lime-water into it, neither the oxygen nor the nitrogen, nor anything else that is in that quantity of air, will make any change in the lime-water. It remains perfectly clear, and no shaking of that quantity of lime-water with that quantity of air in its common state will cause any change; but if I take this bottle with the lime-water, and hold it so as to get the general products of the candle in contact with it, in a very short time we shall have it milky. There is the chalk, consisting of the lime which we used in making the lime-water, combined with something that came from the candle—that other product which we are in search of, and which I want to tell you about to-day. This is a substance made visible to us by its action, which is not the action of the

lime-water either upon the oxygen or upon the nitrogen, nor upon the water itself, but it is something new to us from the candle. And then we find this white powder, produced by the lime-water and the vapour from the candle, appears to us very much like whitening or chalk, and, when examined, it does prove to be exactly the same substance as whitening or chalk. So we are led, or have been led, to observe upon the various circumstances of this experiment, and to trace this production of chalk to its various causes, to give us the true knowledge of the nature of this combustion of the candle—to find that this substance, issuing from the candle, is exactly the same as that substance which would issue from a retort, if I were to put some chalk into it with a little moisture, and make it red-hot: you would then find that exactly the same substance would issue from it as from the candle.

20. Preparation of Carbon Dioxide (Carbonic Acid Gas)

But we have a better means of getting this substance, and in greater quantity, so as to ascertain what its general characters are. We find this substance in very great abundance in a multitude of cases where you would least expect it. All limestones contain a great deal of this gas which issues

from the candle, and which we call *carbonic acid*. All chalks, all shells, all corals contain a great quantity of this curious air. We find it fixed in these stones; for which reason Dr. Black called it "fixed air"—finding it in these fixed things like marble and chalk. He called it fixed air, because it lost its quality of air, and assumed the condition of a solid body. We can easily get this air from marble. Here is a jar containing a little hydrochloric acid, and here is a taper which, if I put it into that jar, will show only the presence of common air. There is, you see, pure air down to the bottom; the jar is full of it. Here is a substance—marble, a very beautiful and superior marble—and if I put these pieces of marble into the jar, a great boiling apparently goes on. That, however, is not steam—it is a gas that is rising up; and if I now search the jar by a candle, I shall have exactly the same effect produced upon the taper as I had from the air which issued from the end of the chimney over the burning candle. It is exactly the same action, and caused by the very same substance that issued from the candle; and in this way we can get carbonic acid [1] in great abundance. We also find that this gas is not merely contained in marble. Here is a flask in which I have put some common whitening—chalk, which has been washed in water and deprived of its coarser particles, and is so supplied to the plasterer as whitening. This flask is fitted

[1] Faraday used this name instead of carbonic acid gas, or carbon dioxide.

with a rubber stopper through which a thistle funnel and a delivery tube pass. The acid is poured down the funnel and the gas escapes along the delivery tube. It is a very heavy gas, so I shall collect it by downward displacement of air. It could not be collected over water as it is soluble in that liquid. I can use practically any acid to liberate carbon dioxide from chalk, etc.; for example hydrochloric, nitric or sulphuric acid. I have here some strong sulphuric acid, which is the acid you might have to use if you were to make these experiments (only, in using this acid with limestone, the body that is produced is an insoluble substance, whereas the hydrochloric acid produces a soluble substance that does not so much thicken the water). And you will seek out a reason why I take this kind of apparatus for the purpose of showing this experiment. I am evolving in this large jar carbonic acid, exactly the same in its nature and properties as the gas which we obtained from the combustion of the candle in the atmosphere. And no matter how different the two methods by which we prepare this carbonic acid, you will see, when we get to the end of our subject, that it is all exactly the same, whether prepared in the one way or in the other.

21. Properties of Carbon Dioxide

We will now proceed to the next experiment with regard to this gas. What is its nature? Here is one of the vessels full, and we will try it, as we have done so many other gases, by combustion. You see it is not combustible, nor does it support combustion. Then, you know that it has an effect, and becomes white in contact with lime-water; and when it does

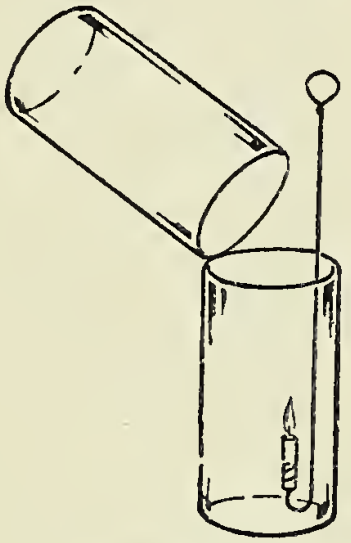


Fig. 30

become white in that way, it becomes one of the constituents to make carbonate of lime or limestone.

The next thing I must show you is, that it really does dissolve a little in water. I have been bubbling this gas through water for a considerable time, and by this time we shall find that we have this substance

dissolved in the water. If I take a glass and draw off some of the water, I find that it tastes a little acid to the mouth: it is impregnated with carbonic acid; and if I now apply a little lime-water to it, that will give us a test of its presence. This water will make the lime-water turbid and white, which is proof of the presence of carbonic acid.

Fig. 30A

Then it is a very weighty gas—it is heavier than the atmosphere. I have put their respective weights at the lower part of this table, along with, for comparison, the weights of the other gases we have been examining:

	Pint	Cubic Foot
Hydrogen . . .	$\frac{3}{4}$ grain	$\frac{1}{12}$ ounce
Oxygen . . .	$11\frac{9}{10}$ grains	$1\frac{1}{3}$,,
Nitrogen . . .	$10\frac{4}{10}$,,	$1\frac{1}{6}$,,
Air	$10\frac{7}{10}$,,	$1\frac{1}{6}$,,
Carbonic acid . .	$16\frac{1}{3}$,,	$1\frac{9}{10}$,,

A pint of it weighs $16\frac{1}{3}$ grains, and a cubic foot weighs $1\frac{9}{10}$ ounce, almost two ounces. You can see by many experiments that this is a heavy gas. Suppose I take a glass containing nothing else but air, and from this vessel containing the carbonic acid I attempt to pour a little of this gas into that glass. (Fig. 30.) I wonder whether any has gone in or not. I cannot tell by the appearance, but I can by means of lime-

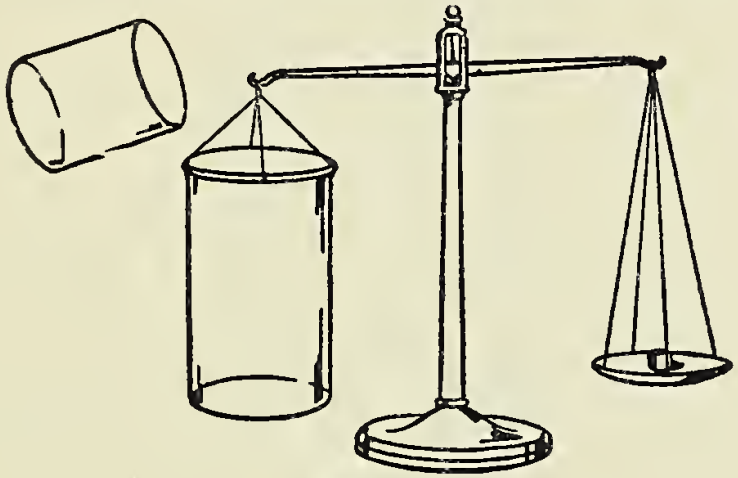


Fig. 31

water or a taper. I will take this little bucket, and put it down into a jar or well of carbonic acid (Fig. 30A) —indeed, we too often have real wells of carbonic acid —and now, if there is any carbonic acid, I must have got to it by this time, and it will be in this bucket, which we will examine with a taper. There it is, you see; it is full of carbonic acid.

There is another experiment by which I will show you its weight. I have here a jar suspended at one end of a balance—it is now equipoised; but when I pour this carbonic acid into the jar on the one side

which now contains air, you will see it sink down at once, because of the carbonic acid that I pour into it. (Fig. 31.) And now, if I examine this jar with the lighted taper, I shall find that the carbonic acid has fallen into it, and it no longer has any power of supporting the combustion. If I blow a soap-bubble, which of course will be filled with air, and let it fall into this jar of carbonic acid, it will float. (Fig. 31A.)

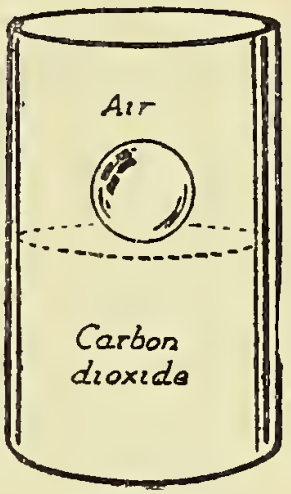


Fig. 31A

But I shall first of all take a little balloon filled with air. I am not quite sure where the carbonic acid gas extends to in this jar. There, you see, we have this bladder floating on the carbonic acid, midway in the jar. If I evolve some more of the carbonic acid, the bladder will be lifted up higher. There it goes, and now I will see whether I can blow a soap bubble on that, and float it in the same way. Ah! it is floating, as the balloon floated, by virtue of the greater weight of the carbonic acid than of the air. And now, having so far given you the history of the carbonic acid—

as to its sources in the candle, as to its physical properties and weight—I shall show you of what it is composed, and where it gets its elements from.

22. The Composition of Carbon Dioxide (Found by Analysis and Synthesis)

I have not yet told you fully and clearly the chemical history of this substance—carbonic acid—as we have it from the candle, and I must now resume that subject. We have seen the products, and the nature of them, as they issue from the candle. We have traced the water to its elements, and now we have to see where are the elements of the carbonic acid supplied by the candle. A few experiments will show this. You remember that, when a candle burns badly, it produces smoke; but if it is burning well, there is no smoke. And you know that the brightness of the candle is due to this smoke, which becomes ignited. Here is an experiment to prove this: so long as the smoke remains in the flame of the candle and becomes ignited, it gives a beautiful light, and never appears to us in the form of black particles. I will light some fuel, which is extravagant in its burning. This will serve our purpose—a little turpentine on a sponge. You see the smoke rising from it, and floating into the air in large quantities; and, remember now, the carbonic acid that we have

from the candle is from such smoke as that. To make that evident to you, I will introduce this turpentine burning on the sponge into a flask where I have plenty of oxygen, the rich part of the atmosphere, and you now see that the smoke is all consumed. This is the first part of our experiment; and now, what follows? The carbon which you saw

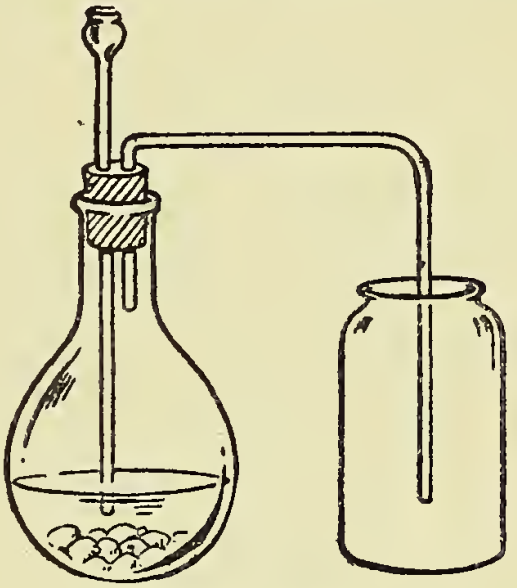


Fig. 31B

flying off from the turpentine flame in the air is now entirely burned in this oxygen, and we shall find that it will, by this rough and temporary experiment, give us exactly the same conclusion and result as we had from the combustion of the candle. The reason why I make the experiment in this manner is solely that I may cause the steps of our demonstration to be so simple that you can never for a moment lose the train of reasoning, if you only pay attention. All the carbon which is burned in oxygen,

or air, comes out as carbonic acid, whilst those particles which are not so burned show you the second substance in the carbonic acid—namely, the carbon—that body which made the flame so bright whilst there was plenty of air, but which was thrown off in excess when there was not oxygen enough to burn it.

I have also to show you a little more distinctly the history of carbon and oxygen, in their union to make carbonic acid. You are now better able to understand this than before, and I have prepared three or four experiments by way of illustration. This jar is filled with oxygen, and here is some carbon which has been placed in a crucible, for the purpose of being made red-hot. I keep my jar dry, and venture to give you a result imperfect in some degree, in order that I may make the experiment brighter. I am about to put the oxygen and the carbon together. That this is carbon (common charcoal pulverised), you will see by the way in which it burns in the air. I am now about to burn it in oxygen gas, and look at the difference. It may appear to you at a distance as if it were burning with a flame; but it is not so. Every little piece of charcoal is burning as a spark, and whilst it so burns it is producing carbonic acid. I specially want these two or three experiments to point out what I shall dwell upon more distinctly by-and-by—that carbon burns in this way, and not as a flame.

Instead of taking many particles of carbon to

burn, I will take a rather large piece, which will enable you to see the form and size, and to trace the effects very decidedly. Here is the jar of oxygen, and here, in this deflagrating spoon, is the piece of charcoal, to which I have fastened a little piece of wood, which I can set fire to, and so commence the combustion, which I could not conveniently do without. (See Fig. 24.) You now see the charcoal burning, but not as a flame (or if there be a flame, it is the smallest possible one, which I know the cause of—namely, the formation of a little carbonic oxide close upon the surface of the carbon). It goes on burning, you see, slowly producing carbonic acid by the union of this carbon or charcoal (they are equivalent terms) with the oxygen. I have here another piece of charcoal, a piece of bark, which has the quality of being blown to pieces exploding as it burns. By the effect of the heat, we shall reduce the lump of carbon into particles that will fly off; still every particle, equally with the whole mass, burns in this peculiar way: it burns as a coal, and not like a flame. You observe a multitude of little combustions going on, but no flame. I do not know a finer experiment than this, to show that carbon burns with a spark.

Here, then, is carbonic acid formed from its elements. It is produced at once; and if we examine it by lime-water, you will see that we have the same substance which I have previously described to you. By putting together 6 parts of carbon by weight

(whether it comes from the flame of a candle or from powdered charcoal) and 16 parts of oxygen by weight, we have 22 parts of carbonic acid; and, as we saw last time, the 22 parts of carbonic acid, combined with 28 parts of lime, produced common carbonate of lime. If you were to examine an oyster-shell, and weigh the component parts, you would find that every 50 parts would give 6 of carbon and 16 of oxygen, combined with 28 of lime. However, I do not want to trouble you with these minutiæ—it is only the general philosophy of the matter that we can now go into. You may say that when charcoal burns, it actually dissolves in the air round about; and if we had perfectly pure charcoal, which we can easily prepare, there would be no residue whatever. When we have a perfectly cleansed and purified piece of carbon, there is no ash left. The carbon burns as a solid dense body, that heat alone cannot change as to its solidity, and yet it passes away into vapour that never condenses into solid or liquid under ordinary circumstances; and what is more curious still, is the fact that the oxygen does not change in its bulk by the solution of the carbon in it. Just as the bulk is at first, so it is at last, only it has become carbonic acid.

There is another experiment which I must give you before you are fully acquainted with the general nature of carbonic acid. Being a compound body, consisting of carbon and oxygen, carbonic acid is a body that we ought to be able to take asunder. And

so we can. As we did with water, so we can with carbonic acid—take the two parts asunder. The simplest and quickest way is to act upon the carbonic acid by a substance that can attract the oxygen from it, and leave the carbon behind. You recollect that I took potassium and put it upon water or ice, and you saw that it could take the oxygen from the hydrogen. Now, suppose we do something of the same kind here with this carbonic acid. You know carbonic acid to be a heavy gas. I will not test it with lime-water, as that will interfere with our subsequent experiments; but I think the heaviness of the gas and the power of extinguishing flame will be sufficient for our purpose. I introduce a flame into the gas, and you see the light is extinguished. Indeed, the gas may, perhaps, put out phosphorus, which, you know, has a pretty strong combustion. Here is a piece of phosphorus heated to a high degree. I introduce it into this gas, and you observe the light is put out; but it will take fire again in the air, because there it re-enters into combustion. Now, let me take a piece of potassium, a substance which, even at common temperatures, can act upon carbonic acid, though not sufficiently for our present purpose, because it soon gets covered with a protecting coat; but if we warm it up to the burning point in air, as we have a fair right to do, and as we have done with phosphorus, you will see that it can burn in carbonic acid, though not so well as in the air, because the carbonic acid contains the oxygen

combined; but it does burn, and takes away the oxygen. If I now put this potassium into water, I find that, besides the potash formed (which you need not trouble about), there is a quantity of carbon produced. I have here made the experiment in a very rough way; but I assure you that if I were to make it carefully, devoting a day to it, instead of five minutes, we should get all the proper amount of charcoal left in the spoon, or in the place where the potassium was burned, so that there could be no doubt as to the result. Here, then, is the carbon obtained from the carbonic acid, as a common black substance; so that you have the entire proof of the nature of carbonic acid as consisting of carbon and oxygen. And now, I may tell you, that *whenever* carbon burns under common circumstances, it produces carbonic acid.

Suppose I take this piece of wood, and put it into a bottle with lime-water. I might shake that lime-water up with wood and the atmosphere as long as I pleased, it would still remain clear as you see it; but suppose I burn the piece of wood in the air of that bottle. You, of course, know I get water. Do I get carbonic acid? Yes, evidently, for the lime-water turns milky; and the carbonic acid gas which converts the lime-water into carbonate of lime must be formed from the carbon which comes from the wood. Indeed, you have yourselves frequently tried a very pretty experiment, by which you may see the carbon in wood. If you take a piece of wood, and partly burn

it, and then blow it out, you have carbon left. There are things that do not show carbon in this way. A candle does not show it, but it contains carbon. Here also is a jar of coal-gas, which produces carbonic acid abundantly. You do not see the carbon, but we can soon show it to you. I will light it, and as long as there is any gas in this cylinder it will go on burning. You see no carbon, but you see a flame; and because that is bright, it will lead you to guess that there is carbon in the flame. But I will show it to you by another process. I have some of the same gas in another vessel, mixed with a body that will burn the hydrogen of the gas, but will not burn the carbon. I will light them with a burning taper, and you perceive the hydrogen is consumed, but not the carbon, which is left behind as a dense black smoke. I hope that by these three or four experiments you will learn to see when carbon is present, and understand what are the products of combustion, when gas or other bodies are thoroughly burned in the air.

23. Respiration and its Analogy to the Burning of a Candle

Now, I must take you to a very interesting part of our subject—to the relation between the combustion of a candle and that living kind of combustion which goes on within us. In every one of us there

is a living process of combustion going on very similar to that of a candle; and I must try to make that plain to you. For it is not merely true in a poetical sense—the relation of the life of man to a taper; and if you will follow, I think I can make this clear. In order to make the relation very plain, I have devised a little apparatus which we can soon build up before you. (Fig. 32.) Here is a board and

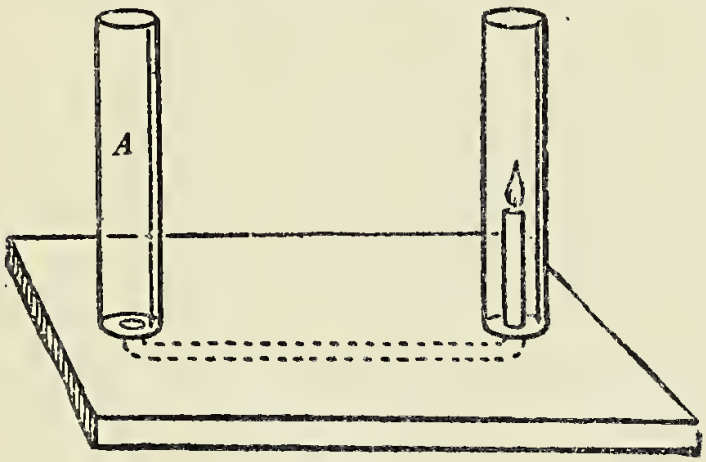


Fig. 32

a groove cut in it, and I can close the groove at the top part by a little cover. I can then continue the groove as a channel by a glass tube at each end, there being a free passage through the whole. Suppose I take a taper or candle (we can now be liberal in our use of the word "candle," since we understand what it means), and place it in one of the tubes; it will go on, you see, burning very well. You observe that the air which feeds the flame passes down the tube A, then goes along the horizontal tube, and ascends the tube at the other end in which the taper

is placed. If I stop the aperture through which the air enters, I stop the supply of air, and consequently the candle goes out. But, now, what will you think of this fact? In a former experiment I showed you the air going from one burning candle to a second candle. If I took the air proceeding from another candle, and sent it down by a complicated arrangement into A, I should put this burning candle out. But what will you say when I tell you that my breath will put out that candle? I do not mean by blowing at all, but simply that the nature of my breath is such that a candle cannot burn in it. I will now hold my mouth over the aperture of A, and without blowing the flame in any way, let no air enter the tube but what comes from my mouth. You see the result. I did not blow the candle out. I merely let the air which I expired pass into the aperture, and the result was that the light went out for want of oxygen, and for no other reason. Something or other—namely, my lungs—had taken away the oxygen from the air, and there was no more to supply the combustion of the candle. It is, I think, very pretty to see the time it takes before the bad air which I breathe into A has reached the candle. The candle at first goes on burning, but so soon as the air has had time to reach it, it goes out. And, now, I will show you another experiment, because this is an important part of our philosophy. I have a bell-jar fitted with a stopper through which passes a piece of glass tubing. I get my mouth over it so

that I can inhale the air. By putting it over water, in the way that you see (Fig. 33), I am able to draw up this air (supposing the cork to be quite tight), take it into my lungs, and throw it back into the jar. We can then examine it, and see the result. You observe, I first take up the air, and then throw

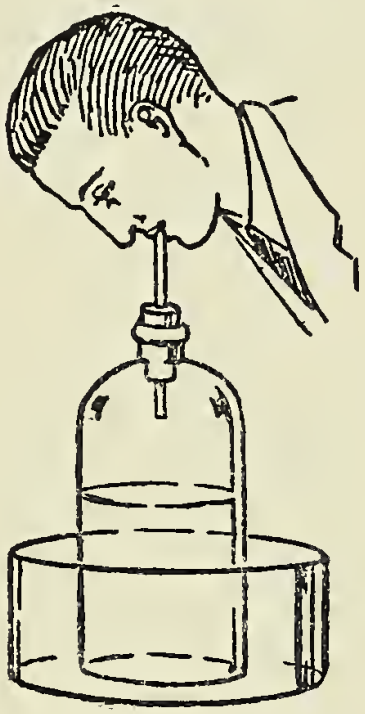


Fig. 33

Bibliothèque du Junior

it back, as is evident from the ascent and descent of the water; and now, by putting a taper into the air, you will see the state in which it is, by the light being extinguished. Even one inspiration, you see, has completely spoiled this air, so that it is no use my trying to breathe it a second time. Now, you understand the ground of the impropriety of many of the arrangements among the houses of the poorer classes, by which the air is breathed over and over

again, for the want of a supply, by means of proper ventilation, sufficient to produce a good result. You see how bad the air becomes by a single breathing; so that you can easily understand how essential fresh air is to us.

To pursue this a little further, let us see what will happen with lime-water. There is a globe (Fig. 34) which contains a little lime-water, and it is so

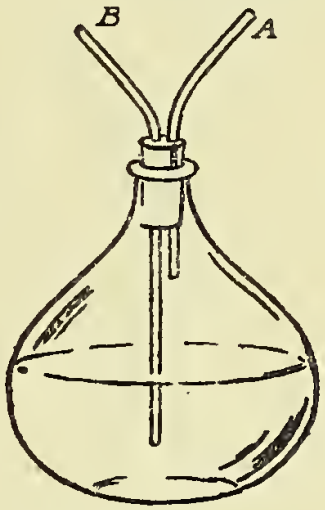


Fig. 34

arranged as regards the pipes, as to give access to the air within, so that we can ascertain the effect of respired or unrespired air upon it. Of course, I can either draw in air (through A), and so make the air that feeds my lungs go through the lime-water, or I can force the air out of my lungs through the tube B, which goes to the bottom, and so show its effect upon the lime-water. You will observe that, however long I draw the external air into the lime-water, and then through it to my lungs, I shall produce no effect

upon the water—it will not make the lime-water turbid; but if I throw the air *from* my lungs through the lime-water, several times in succession, you see how white and milky the water is getting, showing the effect which expired air has had upon it. And now you begin to know that the atmosphere which

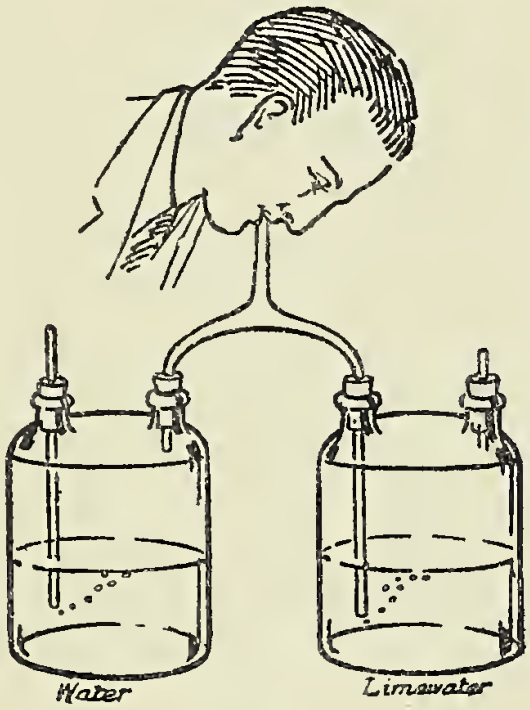


Fig. 35

we have spoiled by respiration is spoiled by carbonic acid, for you see it here in contact with the lime-water.

I have here two bottles, one containing lime-water and the other common water, and tubes which pass into the bottles and connect them. (Fig. 35.) The apparatus is very rough, but it is useful notwithstanding. When I inhale, the air coming in will go to my mouth and lungs, and, when I exhale, it will

pass through the lime-water; so that I can go on breathing and making an experiment, very refined in its nature, and very good in its results. You will observe that the good air has done nothing to the lime-water; in the other case nothing has come to the lime-water but my respiration, and you see the difference in the two cases.

Let us now go a little further. What is all this process going on within us which we cannot do without, either day or night, which is so provided for by the Author of all things that He has arranged that it shall be independent of all will? If we restrained our respiration, as we can to a certain extent, we should destroy ourselves. When we are asleep, the organs of respiration, and the parts that are associated with them, still go on with their action—so necessary is this process of respiration to us, this contact of the air with the lungs. I must tell you, in the briefest possible manner, what this process is. We consume food: the food goes through that strange set of vessels and organs within us, and is brought into various parts of the system, into the digestive parts especially; and alternately the portion which is so changed is carried through our lungs by one set of vessels, while the air that we inhale and exhale is drawn into and thrown out of the lungs by another set of vessels, so that the air and the food come close together, separated only by an exceedingly thin surface: the air can thus act upon the blood by this process, producing precisely

the same results in kind as we have seen in the case of the candle. The candle combines with parts of the air, forming carbonic acid, and evolves heat; so in the lungs there is this curious, wonderful change taking place. The air entering, combines with the carbon (not carbon in a free state, but, as in this case, placed ready for action at the moment), and makes carbonic acid, and is so thrown out into the atmosphere, and thus this singular result takes place: we may thus look upon the food as fuel. Let me take that piece of sugar, which will serve my purpose. It is a compound of carbon, hydrogen, and oxygen, similar to a candle, as containing the same elements, though not in the same proportion—the proportions being as shown in this table:

SUGAR

Carbon	72	
Hydrogen	11	99
Oxygen	88	

This is, indeed, a very curious thing, which you can well remember, for the oxygen and hydrogen are in exactly the proportions which form water, so that sugar may be said to be compounded of 72 parts of carbon and 99 parts of water; and it is the carbon in the sugar that combines with the oxygen carried in by the air in the process of respiration—so making us like candles—producing these actions, warmth, and far more wonderful results besides, for the sustenance of the system, by a most beautiful and

simple process. To make this still more striking, I will take a little sugar; or, to hasten the experiment, I will use some syrup, which contains about three-fourths of sugar and a little water. If I put a little oil of vitriol on it, it takes away the water, and leaves the carbon in a black mass. Sugar, as you know, is food, and here we have absolutely a solid lump of carbon where you would not have expected it. And if I make arangements so as to oxidise the carbon of sugar, we shall have a much more striking result. Here is sugar, and I have here an oxidiser—a quicker one than the atmosphere; and so we shall oxidise this fuel by a process different from respiration in its form, though not different in its kind. It is the combustion of the carbon by the contact of oxygen which the body has supplied to it. If I set this into action at once, you will see combustion produced. Just what occurs in my lungs—taking in oxygen from another source, namely, the atmosphere—takes place here by a more rapid process.

24. Co-operation of the Animal and Vegetable Worlds

You will be astonished when I tell you what this curious play of carbon amounts to. A candle will burn some four, five, six, or seven hours. What, then, must be the daily amount of carbon going up

into the air in the way of carbonic acid! What a quantity of carbon must go from each of us in respiration! What a wonderful change of carbon must take place under these circumstances of combustion or respiration! A man in twenty-four hours converts as much as seven ounces of carbon into carbonic acid; a milch cow will convert seventy ounces, and a horse seventy-nine ounces, solely by the act of respiration. That is, the horse in twenty-four hours burns seventy-nine ounces of charcoal, or carbon, in his organs of respiration, to supply his natural warmth in that time. All the warm-blooded animals get their warmth in this way, by the conversion of carbon, not in a free state, but in a state of combination. And what an extraordinary notion this gives us of the alterations going on in our atmosphere! As much as 5,000,000 pounds, or 548 tons, of carbonic acid is formed by respiration in London alone in twenty-four hours. And where does all this go? Up into the air. If the carbon had been like the lead which I showed you, or the iron which, in burning, produces a solid substance, what would happen? Combustion could not go on. As charcoal burns, it becomes a vapour and passes off into the atmosphere, which is the great vehicle, the great carrier for conveying it away to other places. Then, what becomes of it? Wonderful is it to find that the change produced by respiration, which seems so injurious to us (for we cannot breathe air twice over), is the very life and support of plants and vegetables that grow

upon the surface of the earth. It is the same also under the surface, in the great bodies of water; for fishes and other animals respire upon the same principle, though not exactly by contact with the open air. Fish respire by the oxygen which is dissolved from the air by the water, and form carbonic acid; and they all move about to produce the one great work of making the animal and vegetable kingdoms subservient to each other. And all the plants growing upon the surface of the earth, like that which I have brought here to serve as an illustration, absorb carbon. These leaves are taking up their carbon from the atmosphere, to which we have given it in the form of carbonic acid, and they are growing and prospering. Give them a pure air like ours, and they could not live in it; give them carbon with other matters, and they live and rejoice. This piece of wood gets all its carbon, as the trees and plants get theirs, from the atmosphere, which, as we have seen, carries away what is bad for us and at the same time good for them—what is disease to the one being health to the other. So are we made dependent, not merely upon our fellow-creatures, but upon our fellow-existers, all Nature being tied together by the laws that make one part conduce to the good of another.

25. Fuels

Before we leave the subject of carbon, let us make a few experiments and remarks upon its wonderful condition as regards ordinary combustion. I have shown you that the carbon in burning burns only as a solid body, and yet you perceive that, after it is burned, it ceases to be a solid. There are very few fuels that act like this. It is, in fact, only that great source of fuel, the carbonaceous series, the coals, charcoals, and woods, that can do it. I do not know that there is any other elementary substance besides carbon that burns with these conditions; and if it had not been so, what would happen to us? Suppose all fuel had been like iron, which, when it burns, burns into a solid substance. We could not then have such a combustion as we have in our fireplaces. Here also is another kind of fuel which burns very well—as well as, if not better than, carbon—so well, indeed, as to take fire of itself when it comes in contact with the air. This fuel is lead pyrophorus and can be obtained by heating lead tartrate in a glass tube (closed at one end and drawn out to a fine point at the other) until no more vapours are evolved. The resulting mass consists of finely divided lead and carbon, and when I pour it into the air you see how wonderfully combustible it is. It is very much divided, and is like a heap of coals in the fireplace; the

air can get to its surface and inside, and so it burns. (Fig. 36.) But why does it not burn in that way when I empty the contents of the tube in a heap on to a plate of iron? Simply because the air cannot get to it. Though it can produce a great heat, the great heat which we want in our furnaces and under our

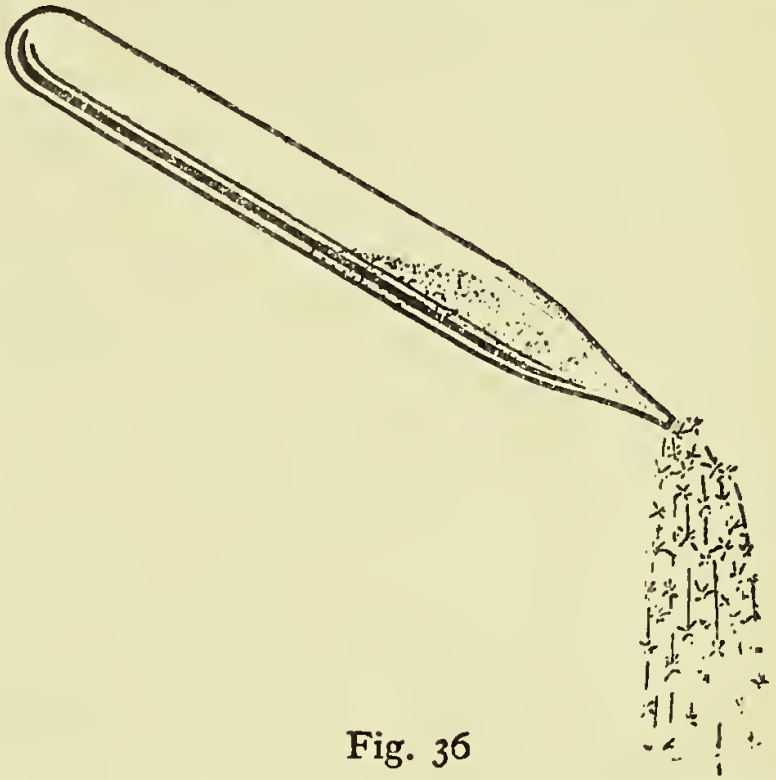


Fig. 36

boilers, still that which is produced cannot get away from the portion which remains unburned underneath, and that portion, therefore, is prevented from coming in contact with the atmosphere, and cannot be consumed. How different is that from carbon! Carbon burns just in the same way as this lead does, and so gives an intense fire in the furnace, or wherever you choose to burn it; but then the body produced by its combustion passes away, and the

remaining carbon is left clear. I showed you how carbon went on dissolving in the oxygen, leaving no ash; whereas, when lead pyrophorus is the fuel, we have actually more ash than fuel, for it is heavier by the amount of the oxygen which has united with it. Thus you see the difference between carbon and lead or iron. If, when the carbon burnt, the product went off as a solid body, you would have had the room filled with an opaque substance, as in the case of the phosphorus; but when carbon burns, everything passes up into the atmosphere. It is in a fixed, almost unchangeable condition before the combustion; but afterwards it is in the form of gas, which is very difficult to produce (though we have succeeded) in a solid or a liquid state.

There is another little point which I must mention before we draw to a close—a point which concerns the whole of these operations, and most curious and beautiful it is to see it clustering upon and associated with the bodies that concern us—oxygen, hydrogen, and carbon, in different states of their existence. I showed you just now some powdered lead, which I set burning; and you saw that the moment the fuel was brought to the air, it acted, even before it got out of the bottle—the moment the air crept in, it acted. Now, there is a case of chemical affinity by which all our operations proceed. When we breathe, the same operation is going on within us. When we burn a candle, the attraction of the different parts one to the other is going on. Here it is going on in this

case of the lead; and it is a beautiful instance of chemical affinity. If the products of combustion rose off from the surface, the lead would take fire, and go on burning to the end; but you remember that we have this difference between charcoal and lead—that, while the lead can start into action at once, if there be access of air to it, the carbon will remain days, weeks, months, or years. The manuscripts of Herculaneum were written with carbonaceous ink, and there they have been for 1800 years or more, not having been at all changed by the atmosphere, though coming in contact with it under various circumstances. Now, what is the circumstance which makes the lead and carbon differ in this respect? It is a striking thing to see that the matter which is appointed to serve the purpose of fuel *waits* in its action: it does not start off burning, like the lead and many other things that I could show you, but which I have not encumbered the table with; but it waits for action. This waiting is a curious and wonderful thing. Candles—those Japanese candles, for instance—do not start into action at once, like the lead or iron (for iron finely divided does the same thing as lead), but there they wait for years, perhaps for ages, without undergoing any alteration. I have here a supply of coal-gas. The jet is giving forth the gas, but you see it does not take fire—it comes out into the air, but it waits till it is hot enough before it burns. If I make it hot enough, it takes fire. If I blow it out, the gas that is issuing forth

waits till the light is applied to it again. It is curious to see how different substances wait—how some will wait till the temperature is raised a little, and others till it is raised a good deal. I have here a little gunpowder and some gun-cotton; even these things differ in the conditions under which they will burn. The gunpowder is composed of carbon and other substances, making it highly combustible; and the gun-cotton is another combustible preparation. They are both waiting, but they will start into activity at different degrees of heat, or under different conditions. By applying a heated wire to them, we shall see which will start first. You see the gun-cotton has gone off, but not even the hottest part of the wire is now hot enough to fire the gunpowder. How beautifully that shows you the difference in the degree in which bodies act in this way! In the one case the substance will wait any time until the associated bodies are made active by heat; but in the other, as in the process of respiration, it waits no time. In the lungs, as soon as the air enters, it unites with the carbon; even at the lowest temperature which the body can bear short of being frozen, the action begins at once, producing the carbonic acid of respiration: and so all things go on fitly and properly. Thus you see the analogy between respiration and combustion is rendered still more beautiful and striking.

Indeed, all I can say to you at the end of these lectures (for we must come to an end at one time or

other) is to express a wish that you may, in your generation, be fit to compare to a candle; that you may, like it, shine as lights to those about you; that, in all your actions, you may justify the beauty of the taper by making your deeds honourable and effectual in the discharge of your duty to your fellow men.

PROFESSOR TYNDALL ON FARADAY

THE outward and visible signs of fame were of less account to Faraday than to most men. He had been loaded with scientific honours from all parts of the world. Without, I imagine, a dissentient voice, he was regarded as the prince of the physical investigators of the present age. The highest scientific position in this country he had, however, never filled. When the late excellent and lamented Lord Wrottesley resigned the presidency of the Royal Society, a deputation from the council, consisting of his lordship, Mr. Grove, and Mr. Gassiot, waited upon Faraday, to urge him to accept the president's chair. All that argument or friendly persuasion could do was done to induce him to yield to the wishes of the council, which was also the unanimous wish of scientific men. A knowledge of the quickness of his own nature had induced in Faraday the habit of requiring an interval of reflection, before he decided upon any question of importance. In the present instance he followed his usual habit, and begged for a little time.

On the following morning, I went up to his room, and said on entering that I had come to him with

some anxiety of mind. He demanded its cause, and I responded, "Lest you should have decided against the wishes of the deputation that waited on you yesterday." "You would not urge me to undertake this responsibility," he said. "I not only urge you," was my reply, "but I consider it your bounden duty to accept it." He spoke of the labour that it would involve; urged that it was not in his nature to take things easy; and that if he became president, he would surely have to stir many new questions, and agitate for some changes. I said that in such cases he would find himself supported by the youth and strength of the Royal Society. This, however, did not seem to satisfy him. Mrs. Faraday came into the room, and he appealed to her. Her decision was adverse, and I deprecated her decision. "Tyndall," he said at length, "I must remain plain Michael Faraday to the last; and let me now tell you, that if I accepted the honour which the Royal Society desires to confer upon me, I would not answer for the integrity of my intellect for a single year." I urged him no more, and Lord Wrottesley had a most worthy successor in Sir Benjamin Brodie.

After the death of the Duke of Northumberland, our board of managers wished to see Mr. Faraday finish his career as President of the Institution which he had entered on weekly wages more than half a century before. But he would have nothing to do with the presidency. He wished for rest, and the reverent affection of his friends was to him

infinitely more precious than all the honours of official life.

. . . . . .

In the year 1835, Sir Robert Peel wished to offer Faraday a pension, but that great statesman quitted office before he was able to realise his wish. The minister who founded these pensions intended them, I believe, to be marks of honour which even proud men might accept without compromise of independence. When, however, the intimation first reached Faraday, in an unofficial way, he wrote a letter announcing his determination to decline the pension; and stating that he was quite competent to earn his livelihood himself. That letter still exists, but it was never sent, Faraday's repugnance having been overruled by his friends. When Lord Melbourne came into office, he desired to see Faraday; and probably in utter ignorance of the man—for, unhappily for them and us, ministers of state in England are only too often ignorant of great Englishmen—his Lordship said something that must have deeply displeased his visitor.

Faraday quitted the minister with his own resolves, and that evening he left his card and a short and decisive note at the residence of Lord Melbourne, stating that he had manifestly mistaken his lordship's intention of honouring science in his person, and declining to have anything whatever to do with the proposed pension. The good-humoured

nobleman at first considered the matter a capital joke; but he was afterwards led to look at it more seriously. An excellent lady, who was a friend both to Faraday and the minister, tried to arrange matters between them; but she found Faraday very difficult to move from the position he had assumed. After many fruitless efforts, she at length begged of him to state what he would require of Lord Melbourne to induce him to change his mind. He replied, " I should require from his lordship what I have no right or reason to expect that he would grant—a written apology for the words he permitted himself to use to me." The required apology came, frank and full, creditable, I thought, alike to the prime minister and the philosopher.

Considering the enormous strain imposed on Faraday's intellect, the boy-like buoyancy even of his later years was astonishing. He was often prostrate, but he had immense resiliency, which he brought into action by getting away from London whenever his health failed. I have already indicated the thoughts which filled his mind during the evening of his life. He brooded on magnetic media and lines of force; and the great object of the last investigation he ever undertook was the decision of the question whether magnetic force requires *time* for its propagation. How he proposed to attack this subject we may never know. But he has left some beautiful apparatus behind; delicate wheels and pinions, and associated mirrors, which were to have been employed

in the investigation. The mere conception of such an inquiry is an illustration of his strength and hopefulness, and it is impossible to say to what results it might have led him. But the work was too heavy for his tired brain. It was long before he could bring himself to relinquish it, and during this struggle he often suffered from fatigue of mind. It was at this period, and before he resigned himself to the repose which marked the last two years of his life, that he wrote to me the following letter—one of many priceless letters now before me—which reveals, more than anything another pen could express, the state of his mind at the time. I was sometimes censured in his presence for my doings in the Alps, but his constant reply was, " Let him alone, he knows how to take care of himself." In this letter, anxiety on this score reveals itself, for the first time.

HAMPTON COURT, *August* 1, 1864.

MY DEAR TYNDALL,—I do not know whether my letter will catch you, but I will risk it, though feeling very unfit to communicate with a man whose life is as vivid and active as yours; but the receipt of your kind letter makes me to know that though I forget, I am not forgotten, and though I am not able to remember at the end of a line what was said at the beginning of it, the imperfect marks will convey to you some sense of what I long to say. We had heard of your illness through Miss Moore, and I was therefore very glad to learn that you are now quite well; do not run too many risks or make your happiness depend too much upon dangers, or the hunting of them. Sometimes the very thinking of you, and what you may be about, wearies

me with fears, and then the cogitations pause and change, but without giving me rest. I know that much of this depends upon my own worn-out nature, and I do not know why I write it, save that when I write to you I cannot help thinking it, and the thoughts stand in the way of other matter.

. . . . . .

See what a strange desultory epistle I am writing to you, and yet I feel so weary that I long to leave my desk and go to the couch.

My dear wife and Jane desire their kindest remembrances: I hear them in the next room: . . . I forget —but not you, my dear Tyndall, for I am ever yours,

M. FARADAY.

This weariness subsided when he relinquished his work, and I have a cheerful letter from him, written in the autumn of 1865. But towards the close of that year he had an attack of illness, from which he never completely rallied. He continued to attend the Friday evening meetings, but the advance of infirmity was apparent to us all. Complete rest became finally essential to him, and he ceased to appear among us. There was no pain in his decline to trouble the memory of those who loved him. Slowly and peacefully he sank towards his final rest, and when it came, his death was a falling asleep. In the fullness of his honours and of his age he quitted us; the good fight fought, the work of duty—shall I not say of glory—done. The "Jane" referred to in the foregoing letter is Faraday's niece, Miss Jane Barnard, who, with an affection raised almost to

religious devotion, watched him and tended him to the end.

I saw Mr. Faraday for the first time on my return from Marburg in 1850. I came to the Royal Institution, and sent up my card, with a copy of the paper which Knoblauch and myself had just completed. He came down and conversed with me for half-an-hour. I could not fail to remark the wonderful play of intellect and kindly feeling exhibited by his countenance. When he was in good health the question of his age would never occur to you. In the light and laughter of his eyes you never thought of his grey hairs. He was then on the point of publishing one of his papers on magne-crystallic action, and he had time to refer in a flattering note to the memoir I placed in his hands. I returned to Germany, worked there for nearly another year, and in June, 1851, came back finally from Berlin to England. Then, for the first time, and on my way to the meeting of the British Association, at Ipswich, I met a man who has since made his mark upon the intellect of his time; who has long been, and who by the strong law of natural affinity must continue to be, a brother to me. We were both without definite outlook at the time, needing proper work, and only anxious to have it to perform. The chairs of natural history and of physics being advertised as vacant in the university of Toronto, we applied for them, he for the one, I for the other; but, possibly guided by a prophetic instinct, the university authorities declined

having anything to do with either of us. If I remember aright, we were equally unlucky elsewhere.

One of Faraday's earliest letters to me had reference to this Toronto business, which he thought it unwise in me to neglect. But Toronto had its own notions, and in 1853, at the instance of Dr. Bence Jones, and on the recommendation of Faraday himself, a chair of physics at the Royal Institution was offered to me. I was tempted at the same time to go elsewhere, but a strong attraction drew me to his side. Let me say that it was mainly his and other friendships, precious to me beyond all expression, that caused me to value my position here more highly than any other that could be offered to me in this land. Nor is it for its honour, though surely that is great, but for the strong personal ties that bind me to it, that I now chiefly prize this place. You might not credit me were I to tell you how lightly I value the honour of being Faraday's successor compared with the honour of being Faraday's friend. His friendship was energy and inspiration; his "mantle" is a burden almost too heavy to be borne.

Sometimes during the last year of his life, by the permission or invitation of Mrs. Faraday, I went up to his rooms to see him. The deep radiance, which in his time of strength flashed with such extraordinary power from his countenance, had subsided to a calm and kindly light, by which my latest memory of him is warmed and illuminated. I knelt one day beside him on the carpet and placed my hand upon

his knee; he stroked it affectionately, smiled, and murmured, in a low soft voice, the last words that I remember as having been spoken to me by Michael Faraday.

It was my wish and aspiration to play the part of Schiller to this Goethe: and he was at times so strong and joyful—his body so active, and his intellect so clear—as to suggest to me the thought that he, like Goethe, would see the younger man laid low. Destiny ruled otherwise, and now he is but a memory to us all. Surely no memory could be more beautiful. He was equally rich in mind and heart. The fairest traits of a character sketched by Paul, found in him perfect illustration. For he was "blameless, vigilant, sober, of good behaviour, apt to teach, not given to filthy lucre." He had not a trace of worldly ambition; he declared his duty to his sovereign by going to the levee once a year, but beyond this he never sought contact with the great. The life of his spirit and of his intellect was so full that the things which men most strive after were absolutely indifferent to him. "Give me health and a day," says the brave Emerson, "and I will make the pomp of emperors ridiculous." In an eminent degree Faraday could say the same. What to him was the splendour of a palace compared with a thunderstorm upon Brighton downs?—what among all the appliances of royalty to compare with the setting sun? I refer to a thunderstorm and a sunset, because these things excited a kind of ecstasy in

his mind, and to a mind open to such ecstasy the pomps and pleasures of the world are usually of small account. Nature, not education, rendered Faraday strong and refined. A favourite experiment of his own was representative of himself. He loved to show that water in crystallising excluded all foreign ingredients, however intimately they might be mixed with it. Out of acids, alkalis, or saline solutions, the crystal came sweet and pure. By some such natural process in the formation of this man, beauty and nobleness coalesced, to the exclusion of everything vulgar and low. He did not learn his gentleness in the world, for he withdrew himself from its culture; and still this land of England contained no truer gentleman than he. Not half his greatness was incorporate in his science, for science could not reveal the bravery and delicacy of his heart.

But it is time that I should end these weak words, and lay my poor garland on the grave of this

JUST AND FAITHFUL KNIGHT OF GOD.

BIBLIOTHEQUE
du
COLLEGE SAINT-JEAN
EDMONTON ALBERTA

MADE AT THE TEMPLE PRESS LETCHWORTH IN GREAT BRITAIN

Veuillez rapporter ce volume avant ou à la dernière date ci-dessous indiquée.

Please return on or before the last date stamped below.

SEP 28 1952

"Entrepôt"

GC
16
F2

QC 16 F2 c.1
Faraday, Michael.
The chemical history of a cand
FSJ

0 0004 8028 401

A2150